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THE MANCHESTER

STEAM USERS' ASSOCIATION.

ESTABLISHED 1854.

MEMORANDUM BY CHIEF ENGINEER FOR THE YEAR 1903.

MANCHESTER:

TAYLOR GARNETT, EVANS, & CO., LTD., BLACKFRIARS STREET: ALSO AT REDDISH AND LONDON.

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MANCHESTER STEAM USERS' ASSOCIATION.

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MEMORANDUM BY CHIEF ENGINEER.

December, 1903.

TO THE EXECUTIVE COMMITTEE.

GENTLEMEN,

In compliance with a request received from the Institution of Mechanical Engineers, you instructed me in 1901 to make further inquiries into the working of Water Softeners. The work has now been completed, and a Paper dealing with the subject has been read and discussed at a meeting of the above-named Institution, whose Council have kindly allowed the Paper, with its numerous diagrams, to be reprinted for the use of this Association, which has accordingly been done.

The Paper deals with the various scale-forming constituents of feed waters, their effect on boilers, and the method of removing them.

I also beg to inform you that the sum of £150 which you granted to the National Physical Laboratory for instruments with which to investigate the specific heat of superheated steam has been accepted by them, and the inquiry is now being carried out.

I am, Gentlemen,

Yours faithfully,

C. E. STROMEYER,

Chief Engineer.

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The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

The Institution of Mechanical Engineers.

AN INQUIRY INTO THE WORKING OF VARIOUS WATER-SOFTENERS.

By Mr. C. E. STROMEYER, *Member*, of Manchester, and Mr. W. B. BARON, of Manchester.

It has frequently been stated that scale seriously reduces the heat efficiency of boilers, and experiments have been made which seem to prove this assertion, but it will be found that they have been carried out on wrong lines, and they only prove that scale very seriously interferes with the transmission of heat if the heat source, usually a flame, is of equal temperature over the whole surface. In a boiler the temperatures vary from 3,000° to 4,000° F. at the furnace, down to 500° to 1,000° F., where the gases leave the boiler. Let us take a simple case, assuming for convenience of calculation that the heat transmission from flame to boiler-plate is proportional to the difference of temperatures. Let the ratio of air to fuel be as 20 to 1; let the air temperature be 80° F., then the flame-temperature will be 3,000° F. If the steam-temperature is 380° F., the maximum temperature of the furnace-plates will, in the above example, be only 20° F. higher than that of the steam, viz., 400° F. Now let it be assumed that the heating surface is covered with scale $\frac{1}{8}$ inch thick; then, if the same quantity of heat were transmitted through the coated furnace-plates as through the clean ones, the temperature

difference between one side of the scale and the fire side of the furnace would be 350° F., and the temperature of the plate would be 730° F. It is, however, clear that as the boiler-plate is hotter than in the first example, less heat will be transmitted to it and the temperature gradient in the scale will be less steep. Naturally also the flame will not get cooled so rapidly, and its temperature, as it reaches the next portion of heating surface, will be higher than before. The temperature distributions will therefore be roughly as follows :—

TABLE 1.

Temperature Distribution in a Boiler.

Square feet of heating surface per pound of fuel per hour . . .	0	¼	½	1	2	4	8
	Boiler with plates free from scale.						
Flame and flue temperature . °F.	3000	2421	1961	1335	728	426	381
Maximum plate temperature . °F.	400	396	392	387	383	381	380
Total heat transmitted . per cent.	0	19·8	35·6	57·0	77·8	89 2	89·7
	Boiler with scale ⅛ inch thick.						
Flame and flue temperature . °F.	3000	2484	2070	1471	835	459	384
Maximum plate temperature . °F.	691	630	581	510	434	389	382
Total heat transmitted . per cent.	0	17·5	31·8	52·4	74·2	87·0	89·5

Boilers are generally designed to have 1½ to 2 square feet of heating surface per pound of fuel burnt per hour under ordinary working conditions. Four square feet in Table 1 represents a lightly worked boiler, and ¼ square foot represents the heating surface usually swept by the flame.

It will be seen from the Table that even for this small value of heating surface to fuel the addition of scale ⅛ inch in thickness only reduces the transmitted heat by 11·6 per cent., whereas when the gases reach the end of a lightly worked boiler, where this value is 4, it is found that the total reduction has fallen to only 2·5 per cent. It may therefore be safely said that even a thick coating of scale does

not materially reduce the efficiency of a boiler. On the other hand, Table 1 shows very clearly that even $\frac{1}{8}$ inch of wet scale raises the temperature of the furnace-plate in this case by nearly 300° F.

In this particular instance there is therefore danger that the furnace has been sufficiently weakened by heat to be nearly collapsing. Scale is thus a serious danger, and, as is well known, has frequently caused accidents. It will be noticed that in clean boilers the temperature of the furnace-plate is nearly the same as that of the water, whereas in the scaly boiler the excess temperature is about one-tenth of that of the flame. If, therefore, in the first case the furnace door is opened and cold air is admitted, the excess temperature of the furnace-plate can at most be reduced 20° F., causing a contraction of only $\frac{1}{90}$ inch in 8 feet, whereas cold air admitted to the furnace of the scaly boiler will effect a rapid reduction of about 311° F. accompanied by a contraction of $\frac{1}{6}$ inch in 8 feet, which is a very serious matter. In fact, in a rigid structure these two strains would be accompanied by stresses of 1·5 and 22 tons respectively. Boilers are elastic, but a large fraction of these stresses certainly make their appearance every time that a furnace door is opened, say once every half-hour, or 6,000 times a year. No wonder, therefore, that in high-pressure boilers, which are necessarily more rigid than low-pressure ones, this constant straining leads to grooving at the furnace flanges. With scale $\frac{1}{4}$ inch thick the stresses would be nearly doubled.

It is thus seen that scale does not materially reduce the efficiency of a boiler, but it seriously increases its wear and tear, whereby its life is considerably reduced. It also endangers the safety of boilers. The same remarks apply to coatings of grease due to feeding the boiler with water containing condensed steam from the engine. It is, therefore, desirable to remove all scale-forming impurities from the feed-water. These impurities are suspended matter, carbonate of lime, sulphate of lime, magnesium salts and grease. One has also to be on one's guard against introducing large quantities of soluble salts, as these concentrate when the water evaporates, until thick scales of crystals are formed.

Let us examine the behaviour of these various impurities.

Suspended Matter is often organic, and appears to have a beneficial effect on such mineral precipitates as may be formed by combining with them and forming loose sediment, which is easily dealt with in water softeners, or it settles down as mud in boilers. Some suspended matter, such as fine sand and more particularly paper pulp, settles on the furnaces and leads to collapses.

Carbonate of Lime is the chief cause of Temporary Hardness.—Its chemical formula is $CaCO_3$. It is practically insoluble in water, but it is easily converted into bicarbonate of lime, having the formula $CaH_2(CO_3)_2$, which is fairly soluble in cold water, and is a constituent of most natural waters. Its second equivalent of carbonic acid is easily removed on boiling, when of course the carbonate of lime is precipitated, forming a scale. The slower this reaction is carried out, the slower the heating, the more chance is there for this carbonate of lime to form crystals—called calcite in mineralogy—which constitute a fairly hard scale, as found in economisers, where the conditions are very favourable to its production. This explains why, in the south of England, where the waters contain much temporary hardness, economisers are very little used, for they would get choked unless the waters be first softened. Waters poor in carbonate of lime but rich in sulphates do not choke the economiser pipes. If the heating is effected rapidly, as for instance when natural waters are pumped direct into the steam space of a boiler, the precipitation of carbonate of lime is so rapid, that only a mud is formed. Another means of converting bicarbonate of lime into carbonate of lime is to add solutions of caustic lime, burnt lime, or caustic soda, in water. For solubilities see Appendix I (page 17). The chemical reaction is as follows:—

$$\begin{array}{cccccc} \text{Bicarbonate of Calcium} & + & \text{Caustic Lime} & = & \text{Carbonate of Lime} & + \text{Water} \\ Ca\,H_2(CO_3)_2 & + & Ca\,O & = & 2\,Ca\,CO_3 & + H_2O \\ \text{Soluble} & & \text{Soluble} & & \text{Insoluble} & \text{Water} \end{array}$$

The second equivalent of the carbonic acid in the bicarbonates of lime and of magnesia is generally called half-bound. Any excess is called free carbonic acid. Of course sufficient lime is required to neutralise both.

In the table of chemical analysis the bicarbonate of lime is split up into carbonate of lime and carbonic acid, because the latter disappears on boiling. One grain of carbonic acid combines with 2·27 grains of carbonate of lime, forming 3·27 grains of bicarbonate of lime. Temporary hardness cannot be entirely removed by lime treatment, because carbonate of lime is not absolutely insoluble.

Sulphate of Lime.—The chemical formula is $CaSO_4$. It is fairly soluble in waters up to the boiling point at atmospheric pressure, but it is less soluble at temperatures corresponding to high pressures of steam, Appendix I (page 17). Because this sulphate of lime cannot be removed by ordinary boiling it is called permanent hardness. One grain of sulphate of lime equals 0·7350 permanent hardness. The result is that if waters containing sulphate of lime are pumped into a boiler, the constant evaporation effects a slow concentration until saturation point is reached, when the sulphate of lime is precipitated so slowly that it crystallises and adheres to all parts of the boiler, but more particularly to the hottest parts; then, whenever the pressure drops—and with it the temperature—part of the precipitate is redissolved, the spaces between the crystals are filled with concentrated solutions of sulphate of lime which crystallises out again on heating, whereby the originally small and loose crystals are enlarged and are firmly cemented together, forming a very hard scale, which can only be removed by chipping or by heating; it is practically gypsum or selenite. If any carbonate of lime is mixed up with the scale, this too gets thoroughly cemented with it.

At the temperatures corresponding to high pressures, water can dissolve only about 20 grains of sulphate of lime per gallon. On cooling down a boiler and letting it stand for some time, the water will dissolve parts of the crystals until there are about 170 grains to the gallon. This dissolving action loosens the scale, which can be easily removed as long as it is wet. If the scale be allowed to dry, all the 170 grains of sulphate crystallise and thereby cement together the loose parts of the scale, making it hard and difficult to remove.

The principle of pumping feed-water into a trough in the steam space of a boiler has several times been patented, but as boiler water can hold up to 20 grains of sulphate of lime in solution, this method is of no benefit with waters having less permanent hardness than 15°.

The sulphate of lime can always be entirely removed by conversion into carbonate of lime. The reaction is as follows:—

$$\begin{matrix} \text{Sulphate of Lime} \\ \text{Ca SO}_4 \\ \text{Soluble} \end{matrix} + \begin{matrix} \text{Carbonate of Soda} \\ \text{Na}_2\text{CO}_3 \\ \text{Soluble} \end{matrix} = \begin{matrix} \text{Carbonate of Lime} \\ \text{Ca CO}_3 \\ \text{Insoluble} \end{matrix} + \begin{matrix} \text{Sulphate of Soda} \\ \text{Na}_2\text{SO}_4 \\ \text{Soluble} \end{matrix}$$

If there is any free or half-bound carbonic acid in the water, and this is generally the case, caustic soda, if available as a waste product, may be used. The caustic soda combines with the carbonic acid to form carbonate of soda, and the reaction is then as sketched above; and the lime which has lost its one equivalent of half-bound carbonic acid is also precipitated. Caustic soda without carbonic acid will not precipitate the sulphate of lime. It is, therefore, wrong to introduce caustic soda into boilers which are fed with water having only permanent hardness. In fact caustic soda should not be pumped into a boiler except together with the cold feed, for as long as the water is cold, the carbonic acid can be fixed, and additions of caustic soda would come too late if made in the boiler.

The above sketched chemical reaction can easily be carried out in water softeners, but the separation of the precipitate is as slow as in the last case, and unless heat is applied, the newly-formed carbonate of lime has to settle for a long time.

Magnesium Salts.—These are found in natural waters as nitrates, chlorides, sulphates, and cause permanent hardness, or as bicarbonate which causes temporary hardness; they are very soluble except the last-named. They all react on soap, and heat will not precipitate them, except the bicarbonate by driving off its carbonic acid. At the high temperatures to be found in boilers a reaction resulting in precipitation of magnesia takes place between the carbonate of lime

and the soluble magnesium salts. The bicarbonate of magnesia can be partly removed by converting it into carbonate of magnesia by the addition of caustic lime.

The reaction in water softeners is as follows:—

Bicarbonate of Magnesia	+	Caustic Lime	=	Carbonate of Magnesia	+	Carbonate of Lime	+ Water
$Mg H_2 (CO_3)_2$	+	Ca O	=	$Mg CO_3$	+	$Ca CO_3$	+ $H_2 O$
Soluble		Soluble		Slightly Soluble		Insoluble	Water

The last traces of magnesium carbonate are removed by adding an excess of lime, the reaction being as follows:—

Carbonate of Magnesia	+	Caustic Lime	+ Water	=	Hydrate of Magnesia	+	Carbonate of Lime
$Mg CO_3$	+	Ca O	+ $H_2 O$	=	$Mg (OH)_2$	+	$Ca CO_3$
Slightly Soluble		Soluble	Water		Insoluble		Insoluble

The other magnesium salts react in a similar way, being easily converted into carbonate and hydrate by the addition of burnt lime and soda ash.

The carbonate of magnesia, $MgCO_3$, is very slightly soluble in water, whereas the hydrate of magnesia $Mg(HO)_2$, is practically insoluble, but being a gelatinous mass it causes serious difficulties in water softeners, more especially by clogging the filters.

Grease.—This is, of course, only found in the waters discharged from jet or surface condensers or from feed-heaters in which steam is condensed. Vegetable and animal fats cause corrosion in boilers, but as they are unsuitable for cylinder lubrication, they are now rarely used and heavy mineral oils have been found to be more suitable. Modern marine practice tends towards the running of engines without any cylinder oil, but factory engines still consume large quantities, and thereby contaminate their feed-water if drawn from the condenser. Part of this grease floats on the water and could be removed by filtration; probably it does little harm if it gets into the boiler, but a small trace is emulsified in the water and is very difficult to deal with. It cannot be separated from water by boiling at atmospheric pressure, but it is completely removed by the conditions which exist in a boiler, and as it adheres to the heating

surfaces it causes overheating which may result in a collapse and certainly increases the wear and tear.

The peculiarity of grease deposits in boilers is that their effect is out of all proportion to their thicknesses. It has been seen that scale of $\frac{1}{8}$ inch thickness will raise the temperature of furnace plates about 300° F. As grease offers ten times more resistance to heat, one would expect that $\frac{1}{80}$ inch would have the same effect as this thickness of scale, but experience shows that the merest trace of grease, certainly less than 1000th inch, or one-tenth of the above, can cause far more serious injury than scale. Various explanations have been attempted. According to one of these, thin films of grease form tough bubbles on the heating surface and prevent the water from keeping it cool. Another view is that grease, either alone or joined to mineral matter, forms an impalpable powder like oxalate of lime and other precipitates, and, like these, retards ebulition. In support of these views we find a fairly well-founded belief that grease in boilers is more injurious if these boilers are clean than if they are coated with mineral scale, and against this view we have the undoubted experience that land boilers with scale at once give trouble if condensed water is used instead of natural water. Increase of pressure above 110 lbs. seems to accentuate this evil; perhaps this may be due to decomposition of magnesium carbonate when this temperature is reached. In any case it is highly desirable to remove every trace of grease from the feed-water. As already stated, this cannot be done by filters; and grease separators, which appear to be rather more efficient, do not remove the last trace of grease.

As yet the only effective method for doing this is to add mineral matter in solution to the condensed water and then to cause precipitation by chemical means. The grease then adheres to the precipitate and can easily be removed by settlement or filtration. Water from jet condensers contains the necessary mineral matter, but this has to be added, if the waters are drawn from surface condensers.

The preceding remarks may be here briefly summarised.

Carbonate of lime forms hard scale in economisers and a soft mud in boilers, unless sulphate of lime is present when it also is

cemented into a scale. Carbonate of lime can be removed by boiling or by adding enough caustic lime or caustic soda to combine with the free and half-bound carbonic acid which holds it in solution.

Sulphate of lime forms no scale in economiser pipes, but it forms a very hard scale in boilers and also cements the carbonate of lime deposits. Its deposition in boilers is due to slow concentration of the water, and it is, therefore, desirable to remove the salt entirely. This can always be done by adding carbonate of soda, which converts it into carbonate of lime.

Carbonate of magnesia generally behaves like carbonate of lime, except that it is slightly more soluble.

The other salts of magnesia are very soluble. They seem to cause corrosion and should be removed. This can be done by treating them like the sulphate of lime by adding carbonate of soda.

Grease should, if possible, be kept out of a boiler. Neither separators nor filters will remove it entirely from feed-waters, but this can be done by mixing them with impure waters and treating them in water softeners.

The cost of raising the temperature of 1,000 gallons of water from 60° to 212° F. is about one shilling when the price of coal is 12*s.* per ton, no matter what the hardness of the water may be.

With waters of 10° temporary hardness 1·14 lbs. of caustic soda of 77 per cent. strength, or 0·8 lb. of burnt lime, will suffice for 1,000 gallons of water. The same quantities will also neutralise all the free carbonic acid represented by 6 grains per gallon. As the prices of caustic soda and lime stand in the ratio of 12*s.* 6*d.* to 1*s.* per cwt., the relative costs of the two treatments would be 1·53 and 0·09 penny per 1,000 gallons, and naturally one would use caustic soda only if it is a waste product and if there is permanent hardness also present. Large proportions of soda, either carbonate or caustic, affect brass fittings.

It requires 1·5 lb. soda ash of 58 per cent. strength to remove 10° permanent hardness out of 1,000 gallons; as the price of this soda is about 5*s.* 6*d.* per cwt. the cost would be about 0·88 penny per 1,000 gallons. The strength of washing soda is about 20 to 22 per cent.

In some water softeners, such as the Archbutt-Deeley, Lassen and Hjort, caustic lime and carbonate of soda are mixed, producing a milky fluid, which consists of caustic soda, free lime or free soda ash, and insoluble carbonate of lime, the latter substance being of course a useless constituent. The cost of the caustic soda so produced would be about 6*s*. per cwt.

The interest and depreciation of the softening plant, the attendant's time, generally only half-an-hour a day, have to be added to the above expenses. If the waters are treated in the boilers—when burnt lime may, of course, not be used—the cost of removal of the scale and the wear and tear of the boiler, due to overheating, have to be added. The following Table 2 shows the relative cost of working installations of from one to seven boilers. Each boiler is supposed to be 8 feet diameter, and to have cost £800, including setting, etc. The interest on the first outlay and on the sums annually set aside for depreciation and renewal is taken at 3 per cent. The best worked boiler using pure or softened water is supposed to last fifty years, and the last boilers on the Table are supposed to last only fifteen years, and have to be opened out and scaled every three months. The other boilers, having each a spare one in the set, are supposed to last the number of years shown in the Table. In each case except the first the water is supposed to be very sedimentary.

It will be seen that according to this estimate, boilers using pure water should not cost more than about £35 per annum, including chemicals in a water softener, whereas the other boilers using sedimentary water and boiler compositions may cost twice and three times as much. The minimum saving, say £30, capitalised at 5 per cent. represents £600, whereas the cost of a water softener per boiler would amount to about £100 to £200.

Turning one's attention to some of the practical difficulties which water softeners have to overcome, the most important of these are the proper adjustment of the supply of chemicals and the removal of the precipitates from the treated waters. If, by suitable chemicals, carbonate of lime is precipitated out of water it is at first in a colloidal condition, its first appearance

TABLE 2.

Hypothetical.

Nature of Feed.		Pure.	Very Sedimentary Water.						
Boilers at work . . .		1	1	2	3	4	5	6	6
Spare boilers . . .		0	1	1	1	1	1	1	0
Assumed life of boilers . .		50	40	40	40	40	30	20	15
Interest on first cost .	£	24	48	72	96	120	144	168	144
Depreciation . . .	£	7	21	32	42	52	100	209	258
Scaling and cleaning @ 30*s.*	£	2	20	39	59	78	78	78	36
Chemicals . . .	£	2	10	20	30	40	50	60	60
Total . . .	£	35	99	153	227	290	372	515	498
Totals per working boiler	£	35	99	71·5	75·7	72·5	74·4	85·8	83*

* The actual cost would be much greater, as the works would be closed down for 4 weeks per annum.

being that of a bluish-white thin starch, which can freely pass through the best chemical filters, and could never be arrested by wood wool, cloth or sponges. If this fluid is allowed to stand for a considerable time, or if it is heated a little, the precipitate settles down, changing to a yellowish colour, and no amount of shaking will again convert it back to its original condition; but even now this precipitate is so fine that it settles down very slowly. According to Professor Wanklyn's experiments this precipitate will settle down in twenty-five minutes through $\frac{3}{4}$ inch of water, which will then be quite clear, whereas it takes eight hours to clear 20 inches of water charged with this precipitate. The rate of settlement is about 1·8 to 2·5 inches per hour. No experiments seem to have been made on hot water.

It is thus understood why very large tanks are necessary when working with cold water, and why even filters will not remove all the precipitated carbonate of lime.

When the softening operation is carried out hot, these settling tanks, as can be seen by comparing various softeners, may be much reduced in size, and filters now become far more effective than before.

In most of the cold-water softeners the treated water moves upwards against the descending sediment, which, being coarse, assists the newly-formed precipitate in settling down. In other softeners, notably in that of Desrumaux, the treated water is made to travel in comparatively thin sheets. Thus by dividing the tower into narrow layers, the precipitate has not to fall very far. This principle may be carried too far, for the thinner and longer the sheet of water, the greater the velocity and the stronger the eddies.

In spite of the use of very large settling tanks, supplemented by filters, there are very few cold-water softeners which can be relied upon to remove all the solid matter which the added chemicals have precipitated, and serious complaints are not infrequently heard that after the installation of a water softener, the injectors or the feed-pipes get choked with scale. Evidently all the chemical precipitates do not settle down thoroughly until the comparatively hot pipes are reached.

To overcome this difficulty the Archbutt-Deeley process is arranged so that the carbonic-acid gas from a stove comes in contact with the treated water and dissolves the trace of precipitate which would have appeared in the pipes. Steam users, however, have a prejudice against deliberately introducing carbonic acid into their boilers, and some at least add very large settling tanks, and do not use the stove. Unquestionably the most effective way of removing the residual precipitate would be to heat the treated water, but as already shown, that is a very expensive remedy.

In practice, magnesia precipitates are still more difficult to deal with than the lime precipitates, because of their gelatinous nature, which although it assists in separating out the carbonate of lime, also retards the settling process, and seriously interferes with the working of filters. Here again heat is a remedy, but only a

partial one, and is very costly. Nevertheless, several of the softeners dealt with in this Paper seem to have removed large quantities of magnesia without choking their filters.

In the Archbutt-Deeley softener, which, due to a sufficiency of lime, has effectively removed nearly all magnesia salts, each new tankful of treated water is mixed with the sediment of the previously treated waters, the settlement being expedited by the adhesion of the old and coarse particles to the new flocculent and gelatinous precipitates. The same principle is adopted in those softeners in which the treated water is led to the bottoms of the settling tanks, and has to pass through previously precipitated mud. Use is also made of the precipitated mud for the removal of grease in the apparatus of Babcock and Wilcox, Boby, Maxim, and Wollaston, in which exhaust steam is introduced. The explanation of the cause of this removal is doubtless to be found in the coagulation of the first-formed colloidal precipitate, which on separating effectively removes both the oil in suspension and in the emulsified state. Wollaston finds that the greasy scum rises upwards, and at the top of his reaction tower a scum tap is fitted, and the exit from this tower to the settling tank is placed some distance below, thereby preventing this scum from contaminating the softened water.

Out of seventeen continuous water softeners dealt with in this Paper fourteen are fitted with filters. Two of these, Bell's and Reisert's, are sand filters. Porter-Clark and the Atkins Co. have cloth filters, and the others have wood wool or sponge filters. Wood wool is cheap and can be renewed, say, twice a year, while sponges have to be cleaned. These removal or cleaning operations are rather tedious, but cannot be entirely obviated. Those filters through which the water passes downward, and on to which the sediment falls, have, of course, to be cleaned much more frequently than those through which the water passes upward.

Cloth filters have to be cleaned by hand. They generally consist of a number of wooden or iron frames, each frame being separated from its neighbour by a piece of cloth. The frames are pressed together by two long bolts. The water enters every alternate frame through a hole in the top side or middle, and is discharged out of

holes in the bottoms of the adjoining frames. The cloths are easily removed by slacking back the nuts on the long bolts. The Atkins Co. filters are circular discs which are brushed clean withou tremoving them.

The second difficulty encountered in practice is that of properly apportioning the chemicals.

It appears that in all water softeners the chemicals are dissolved in water or at least mixed with it, and the introduction of small measured quantities of powdered slaked lime and of powdered soda does not appear to have been tried, and numerous complicated and ingenious contrivances have been devised for overcoming the difficulties which are encountered when using fluids.

Thus, caustic lime, as will be seen by Appendix I (page 17), dissolves only very sparingly in water, the quantity decreasing with rising temperature from 91 grains at 60° F. down to 40 grains at 212° F. At about 70° F. the solubility decreases at the rate of about $\frac{1}{2}$ per cent. for every 1° F. rise of temperature. It requires $1\frac{1}{4}$ grain of caustic lime, or about $\frac{1}{70}$ gallon of lime water, to precipitate the carbonate of lime, which is dissolved in water containing 1 grain of a free carbonic acid, and as this free carbonic acid is rarely less than 7 grains per gallon it is generally necessary to add quite 10 per cent. of lime water. This lime water is prepared by throwing slaked lime into a deep tank and letting unsoftened water flow slowly through the milk of lime in the bottom. If the flow is slow enough, and the tower high enough, the overflow is clear saturated lime water. The relative quantities of lime water to untreated water is regulated by letting both streams emerge from a single tank having adjustable nozzles or weirs. Except that the lime tank must be high, and that it ought to be provided with stirrers near the bottom, this arrangement is a fairly convenient one. It is used by the Atkins Co., Desrumaux, Reisert, and Stanhope.

The apparatus can, of course, be made much smaller if milk of lime, containing say 10 per cent. caustic lime, is used instead of clear lime water, but then it is imperative that this milk of lime should be perpetually stirred, as in the Bell, Doulton, Harris-Anderson and Porter-Clark softeners, nor is it permissible to add

water during the working day, as appears to be the case with the Harris-Anderson softener. The mixture is thereby made weaker and weaker.

In the Lassen and Hjort softener the quantity of milk of lime and soda solution, injected with each tilt of the water trough, is regulated by the duration of the opening of a small valve, but as the head of the re-agent diminishes during the working day, so does the quantity of injected fluid, and it has been found necessary to keep the chemical tank half full. These two examples will suffice to show that, in spite of some advantages, the use of milk of lime is perhaps attended with more difficulties than is the use of lime water.

Most water softeners are provided with small lime-slaking tanks, but this is not an invariable practice, nor does any continuous softener seem to be fitted with a tank in which either soda or caustic soda is dissolved before use; yet it takes some time to dissolve these salts and thoroughly mix the solutions. The addition of the soda to the untreated water is perhaps most easily effected by a small pump, which must be of iron, working in unison with the feed-pump. Scoops and bucket-chains are also used. In all these arrangements the ratio of soda to water is best regulated by varying the strength of the soda solution. The Harris-Anderson softener has a very ingenious arrangement for delivering soda of the right density. It is, however, questionable whether all these extremely ingenious contrivances are at all necessary. They are intended to replace the pump, but have grown so complicated that they are unquestionably now more costly. Pumps for supplying the chemicals are used by Bell, Boby, Maxim, Porter-Clark, and Wollaston. Weirs, whose relative widths can be regulated, are used by Harris-Anderson and Wright. Carefully-gauged holes or taps, whose openings can be regulated, are used by Babcock and Wilcox, Carrod, Desrumaux, Doulton, and ball taps by the Atkins Co. and Tyacke.

Assisted by the above general remarks the sketches of the water softeners, together with their descriptions, Appendix II (page 18), and the analyses of the unsoftened and softened waters (Appendix III, page 54) permit of a fair comparison being made as to the suitability of the various types for special purposes.

Glancing over the analyses, it will be noticed that, with two exceptions, the various users have added too little lime. This cannot be on the ground of expense as lime is very cheap, nor on account of increasing the amount of dissolved solids, for, unlike soda ash or caustic soda, it both decreases the temporary hardness and also the amount of dissolved solids. The cause of the insufficiency of lime is most probably due to an incorrect idea of the functions of the added lime. They are three in number:—

(i.) To combine with the free carbonic acid.

(ii.) To combine with the half-bound carbonic acid.

(iii.) To reduce all the magnesia to hydrate.

In most of the analyses only that represented by (ii.) has been approached. A simple differential soap and colour test, devised by Mr. Baron (Appendix IV, page 62), will permit of better softening-effects being easily attained.

In nine cases out of nineteen an excess of soda has been added. This excess should be avoided, as it tends to corrosion of the brass fittings, especially when in the form of caustic soda or even sodium carbonate.

With regard to those apparatus in which the temporary hardness is supposed to precipitate by the use of steam, it would seem that only prolonged boiling completely evolves the free and half-bound carbonic acid. The result is that caustic soda is generally required to precipitate the permanent hardness and neutralise the still unexpelled carbonic acid. The presence of any magnesia salts also calls for the use of caustic soda or lime as explained above.

The Paper is accompanied by 4 Appendices, which are illustrated by 17 Figs. in the letterpress.

APPENDIX I.

Solubilities.

Temperatures.	Corresponding Steam Pressure.	Chemicals and Experimentors.			
		Calcium Oxide. (Caustic lime.)	Calcium Sulphate.		
		Lamy 1878	Marignac 1874	Poggiale 1879	Tilden and Shenstone —
°Fahr.		Grains per Gallon.			
32	—	96·7	133·0	113·5	—
40	—	94·0	—	—	—
59	—	91·0	—	—	—
64·4	—	—	143·0	—	—
68	—	—	—	168·7	—
75·2	—	—	116·5	—	—
86	—	81·4	—	—	—
95	—	—	—	177·8	—
101·5	—	—	150·3	—	—
111	—	70·1	—	—	—
127·4	—	—	117·0	—	—
140	—	70·8	—	—	—
158	—	—	—	170·8	—
161·6	—	—	140·8	—	—
210·2	—	—	122·6	—	—
212	0	40·2	—	151·9	—
284	37	—	—	—	54·6
323·6	79	—	—	—	39·2
356	131	—	—	—	18·9
464	484	—	—	—	12·6
482	575	—	—	—	12·6

APPENDIX II.

ARCHBUTT-DEELEY WATER SOFTENER.*

The apparatus, Fig. 1, consists of a small chemical tank, a re-action and settling tank combined, a storage tank and a coke stove. The inlet for the untreated water is at the side of the tank about two or three feet above the bottom. The treated water is drawn off the surface by means of a floating discharge. This pipe is connected to the chimney of a coke stove. Steam pipes are led into the chemical tank and an air blast actuated by a steam jet is led into the re-action tank.

Capacity.—2,500 gallons at a time or 1,000 gallons per hour.

Dimensions.—Re-action and settling tank, 8 feet cube; the storage tank is 22 feet long, 17 feet wide, 3 feet 9 inches high, and holds 5,500 gallons; floor space of softening tank 64 square feet. Total floor space, 438 square feet. About 180 of these softeners of various sizes are in use.

Working.—The re-action tank is filled with the untreated water, a definite quantity of burnt lime is put into the chemical tank, slaked, mixed with water and boiled by admitting live steam. The necessary quantity of soda is then added and again boiled. The untreated water is introduced, by means of a steam injector, through the upper one of two sets of pipes near the bottom of the tank. On its passage through the pipes the re-agent is slowly added. By turning a cock, the steam injector is made to drive air through the perforations in the lower pipe in the bottom of the re-action tank. This air effects a thorough mixing of the water and re-agent, and also stirs up the sediment remaining from previous operations, the newly formed sediment readily adheres to it and is quickly settled. This precipitate is occasionally removed by suitable means. The softened water is drawn off through the swivelled floating discharge pipe. While passing down this pipe the water should come in contact with the waste gases from the coke stove and should absorb some carbonic acid. The sample analysed was not carbonated.

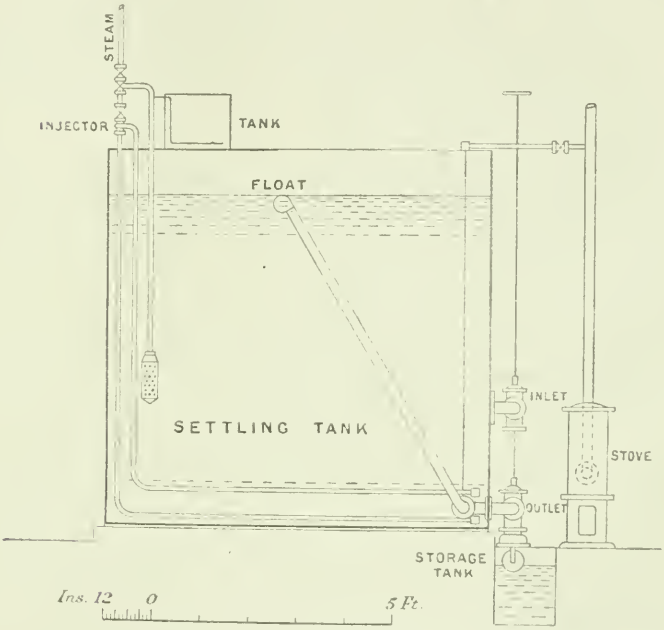
* Proceedings 1898, part 3, page 104.

Supply.—Partly town's water, partly brook.

Chemicals used per 1,000 gallons, 2·5 lbs. lime, 0·6 lb. soda, 0·15 lb. alumino ferric.

The user reports that this apparatus is easily worked and gives satisfactory results. The old boiler scale came off after six weeks' use. Now there is only a slight mud in the boilers. The carbonating is done for every alternate tank.

Fig. 1.—*Archbutt-Deeley*



Result of Analysis.—The supply is the same as that for the Desrumaux apparatus, Fig. 7 (page 31), but was not collected at the same time. A slight excess of lime as well as of soda was added, which had the effect of almost entirely removing the magnesia salts. This sample of water was not carbonated, but the treated water had absorbed 0·63 grain of carbonic acid, probably by contact with the atmosphere.

THE ATKINS CO. WATER SOFTENER.

The apparatus, Fig. 2 (page 21), consists of a lime-slaking tank, a lime-water tank, a settling tank and a tank with revolving filter discs. The settling tank has a central division plate, and over it are placed two troughs, one for mixing the supply with the lime water, the other for collecting the treated water. The supply pipes to the mixing trough and to the bottom of the lime-water tank are controlled by ball-taps.

The filters consist of hollow cast-iron discs covered with perforated sheet zinc and filtering cloths. They are bolted together by means of a hollow shaft which acts as a discharge pipe. Brushes are placed between the discs.

Capacity.—2,500 gallons per hour.

Dimensions.—Settling tank, 7 feet wide, 15 feet long, 5 feet deep. Lime-water tank, 3 feet 6 inches diameter, 8 feet deep. Filter tank, 5 feet 6 inches wide, 6 feet long, 6 feet deep. Floor space, exclusive of lime-slaking tank, 138 square feet.

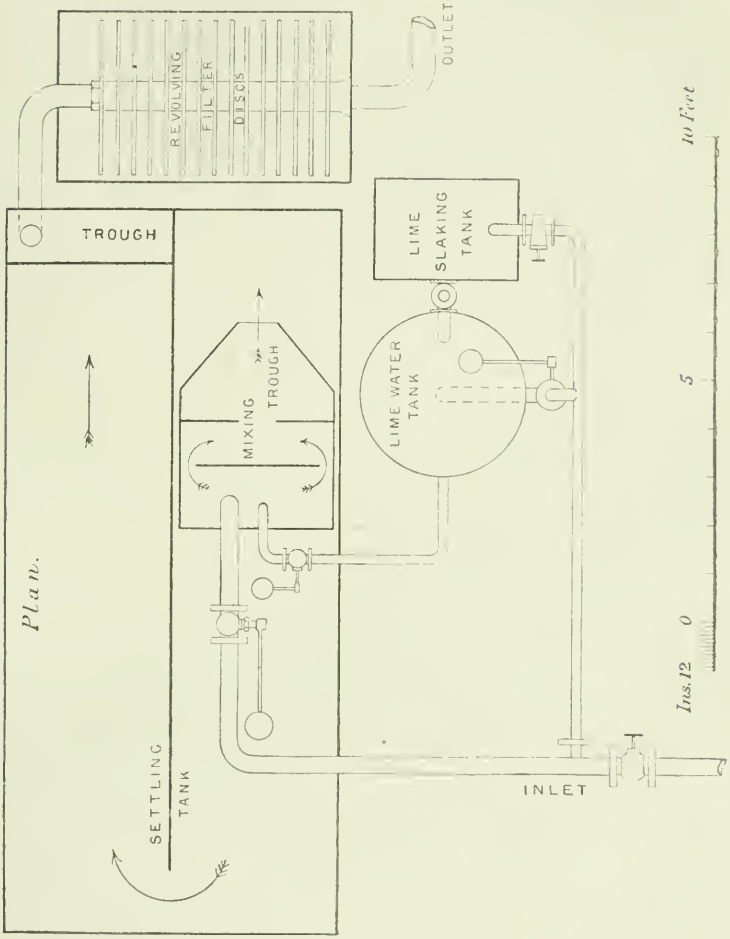
Working.—Slaked lime and water are poured into the lime-water tank, and a small stream of water, regulated by a ball-tap in this tank, enters the bottom of the tank, and clear lime water flows into a mixing trough, on to which the remainder of the water to be treated is poured. The supply and the outflow of the lime water are regulated by ball-taps in the settling tank. The mixed water passes along the settling tank and overflows to the filters. These are cleansed occasionally by giving them a turn, when the brushes remove the sediment. No information was obtained as regards supply, chemicals used or effects on boiler.

Results of Chemical Analysis.—In this case water which had only 3·165° of permanent hardness was only treated for temporary hardness, which was successfully reduced to 2·32°.

BABCOCK AND WILCOX WATER SOFTENER (GUTTMAN).

The apparatus, Fig. 3 (page 23), consists of a chemical tank, a re-action tank, filters and soft-water tank. The supply pipe passes down

Fig. 2.—*The Atkins Co.*



the side of the chemical tank and ends in the bottom of the re-action tank. It has a branch pipe and cock over the chemical tank, and is fitted with valve V, shown on larger scale, which is regulated by the float in the soft-water tank. Live steam enters the re-action tank as shown, through a silent injector; a branch from the steam pipe for occasional use is led into the bottom of the chemical tank. Where exhaust steam is available an additional injector is fitted as shown. Attached to the bottom of the chemical tank is a pipe with two cocks, C_1 for regulating the ratio of soda solution to the feed, and C_2 for regulating the quantity in accordance with the feed drawn off. At the top of the re-action tank is a weir over which the treated water flows into the filter, which consists of a series of boxes filled with wood-wool. The bottoms of these boxes are provided with cocks through which the sludge is drawn off occasionally. The filtered water passes into the soft-water tank, whence it is pumped into the boiler.

Capacity.—5,000 gallons per hour.

Dimensions.—Chemical and re-action tanks, 5 feet 5 inches square, 13 feet high. Filters and soft-water tank, 5 feet 5 inches wide, 17 feet long and 8 feet high, measured over flanges. Total floor space, 122 square feet.

About thirty-five of these softeners of various sizes are in use.

Working.—Enough soda to last for one day is placed in the chemical tank, water is added and steam turned on till all the soda is dissolved. The cock C_1 is opened to suit the density of the soda solution and the impurity of the feed water, and has to be adjusted during working, according to whether the softened water is alkaline or not. The cock C_2 and the feed valve V are actuated by levers from one float in the settling tank, so that the ratio of the amount of chemical and of the water is maintained. The mixture flows into the re-action chamber, where it is mixed with waste steam if available. It is here brought to the boiling point by live steam, which should remove the temporary hardness; the soda removes the permanent hardness. The hot water overflows to the filters, which it passes in half-an-hour, and here the sediment is removed. Some

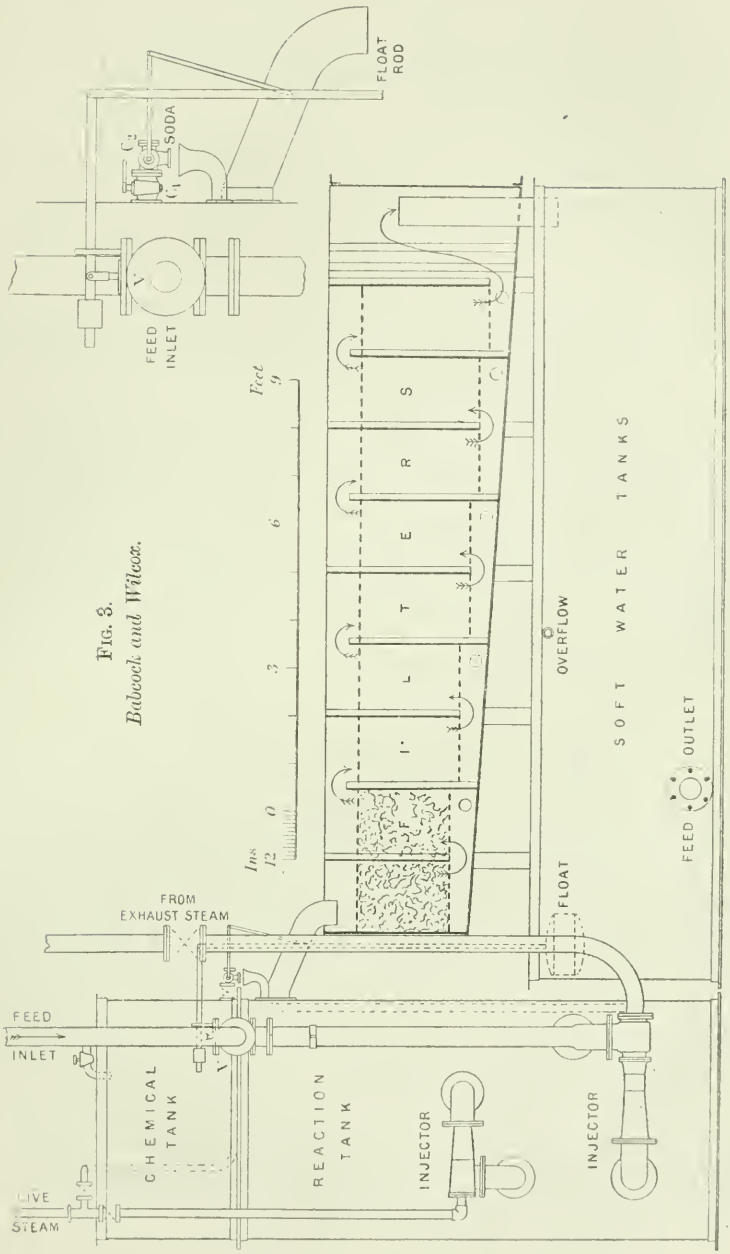


Fig. 3.
Babcock and Wilcox.

sediment collects in the lower tank. The grease from the exhaust steam adheres to the sediment and does not pass the filters.

Supply.—From a reservoir.

Chemicals used.—Soda ash, quantity not stated.

The users report that this softener has worked well for three years and has given every satisfaction, although the water is hard and sometimes acid. No trouble has been experienced with their three water-tube boilers with $1\frac{1}{2}$ in. diameter tubes. All old scale is now removed, and only a little soft mud is formed. On one occasion a little grease was carried into the boilers, but it was found that the filter had not been properly packed.

Result of Chemical Analysis.—The analysis shows that about 60 per cent. condensed steam have been added to the supply. Neither the high temperature nor the chemicals have produced a beneficial effect, for on subtracting the above-mentioned condensed water (see third column of Table of Analysis, page 55), the various constituents and the hardness are practically the same as the supply, except that some added soda has converted all the permanent hardness into temporary hardness.

BELL BROTHERS' WATER SOFTENER.

The apparatus, Fig. 4 (page 25), consists of a mixing tank, a re-action tank, a settling tank and two sand filters. The mixing tank and chemical tanks have mechanically-driven paddles. A pipe leads from the mixing tank through a small pump to the inlet pipe of the untreated water. Another pipe leads from the top of the settling tank to the two filters. The sand filters are provided internally with revolving hollow arms, which on occasion break up and wash the filtering sand.

Capacity.—2,500 gallons per hour.

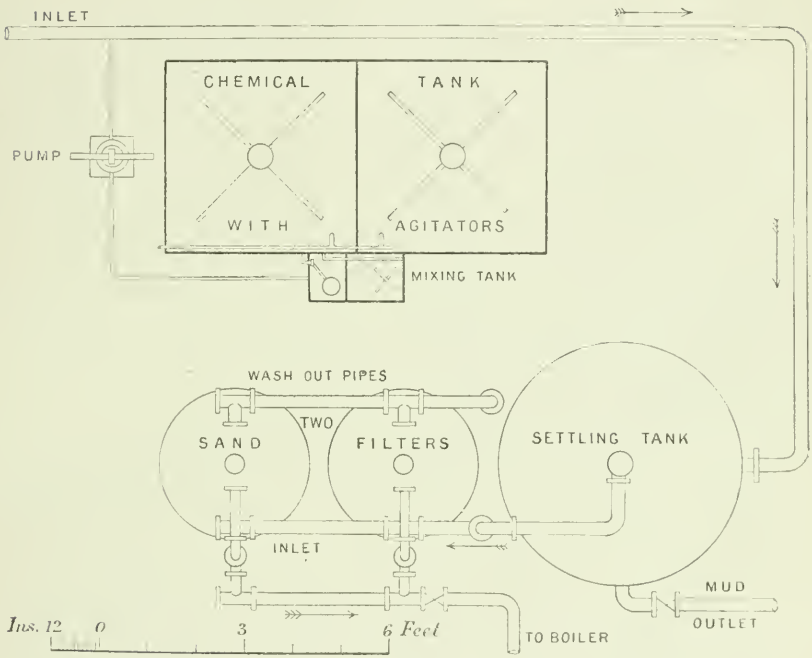
Dimensions.—Two chemical tanks, 4 feet wide, 8 feet long, 4 feet high. Settling tank, 5 feet diameter, 9 feet above ground to top of handwheel. Each sand filter is 3 feet diameter and 8 feet 6 inches high. The floor space is 172 square feet.

About twelve of these softeners of various sizes are in use.

Working.—The chemicals, lime and soda, are placed in their chemical tanks and well stirred. They are then passed in correct proportions into the mixing tank with its stirrer, and pumped into the feed inlet pipe, thence into the settling tank and then into the sand filters. When the pressure gauge indicates that the filters are

Fig. 4.—*Bell Brothers'.*

Plan.



nearly choked the sand is loosened by water pressure from below, and then more water is injected through revolving arms into the body of the sand bed, which is thereby thoroughly washed out. The filters are under a pressure of 160 lbs. per square inch.

Supply.—Well water.

Chemicals used per 1,000 gallons.—2 lbs. alkali and 1·5 lbs. lime.

The users report that the softener works fairly well, but the

pipes get choked too often. The makers affirm this to be due to faulty manipulation.

Result of Chemical Analysis.—By adding an excess of soda the permanent hardness was reduced from 30·9° to nothing. The 2 lbs. of lime, said to have been added, do not appear to have been properly mixed with the supply, and the temporary hardness has for this reason been increased from 5·2° to 6·8°, which may account for the trouble.

Boby Water Softeners: Chevalet Detartariser.

The apparatus, Fig. 5 (page 27), consists of several perforated trays placed one above another and surrounded by a cylindrical shell, the lower part of which is the softened-water tank. At the side of this tank is placed a closed vessel with a float. The latter is connected to the inlet valve and regulates the supply. A pipe for injecting soda solution enters the untreated water-supply pipe. The exhaust pipe from the engines ends in a grease separator attached to the softened-water tank. The outlet for the uncondensed exhaust steam into the atmosphere is at the top of the apparatus, and can be connected to a main condenser which would deliver water free from grease.

Capacity.—3,400 gallons per hour.

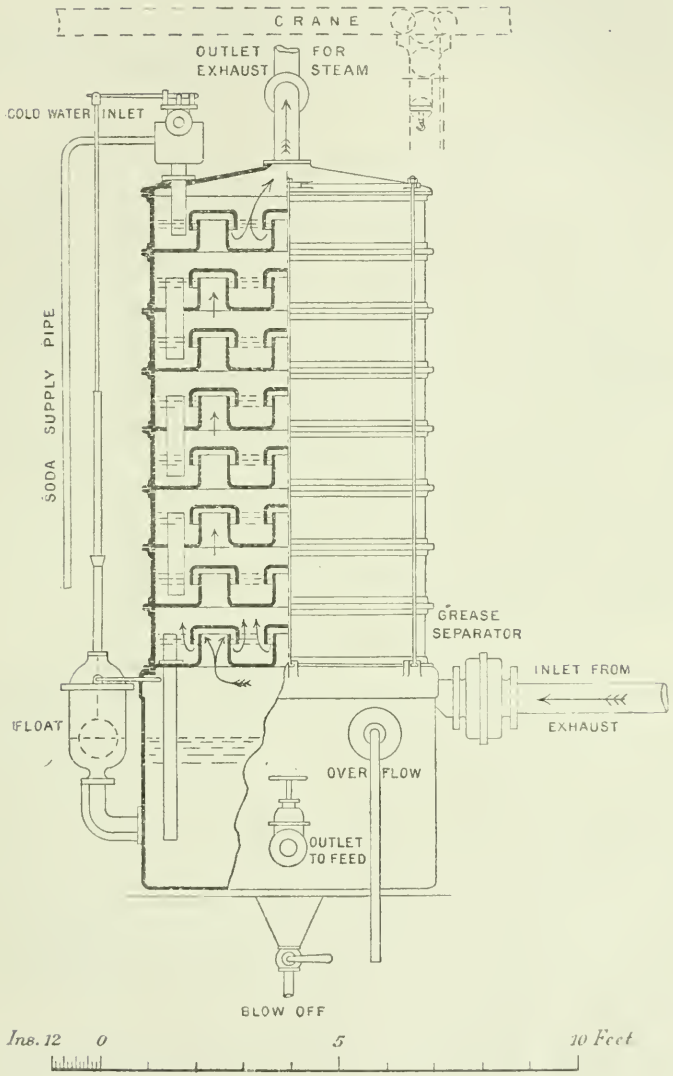
Dimensions.—Diameter of softened-water tank, 6 feet 2 inches. Height to top flange, 15 feet. Total floor space, exclusive of float and soda tank, 37 square feet.

About five hundred of these softeners of various sizes are in use.

Working.—Soda is dissolved in a tank, not shown on the drawing, and the solution is pumped into the water supply which falls on the top trays of the softener. There it comes in contact with the escaping steam and gradually reaches the soft-water tank at the bottom. In its downward passage the water is in contact with the exhaust steam, acquires its temperature, partly condenses it. The heat effects a precipitation of the carbonate of lime, and the soda precipitates the sulphate of lime. These precipitates, mixed with grease, adhere to the trays. Occasionally the apparatus is taken to pieces and the deposit removed. The joints are easily remade with

Fig. 5.

Boby, Chevalet Detartariser.



putty. The feed-pump, drawing from the softened-water tank, actuates the soda pump, and thus the ratio of the chemical to the feed-water is kept constant.

The exhaust steam, after passing the grease extractor, comes first in contact with the softened water, and must inevitably impart to it traces of grease.

Supply.—Well water.

Chemicals used.—Soda, quantity not stated.

The users report that after three months' use it takes three days to clean the apparatus and to remove 2 tons of scale. No grease has been noticed in the feed, and no scale is formed in the boiler.

Result of Chemical Analysis.—The analysis shows that 27 per cent. condensed steam was added to the supply. Subtracting this addition, the effect of the heat and the carbonate of soda is shown in the third column of the Table of Analysis (page 55), where it will be seen that the temporary and permanent hardnesses have been reduced from 22·7° and 12·6° to 4·6° and 4·22°. Only a small part of the magnesia has been removed. Better results would have been obtained by the use of caustic soda instead of carbonate of soda. Heat alone does not appear to be able to reduce the temporary hardness to a minimum.

CARROD WATER SOFTENER.

The apparatus, Fig. 6 (page 29), consists of two chemical tanks, one mixing tank, and a settling tank and filter combined, and a distributor. The water-supply pipe has a hand-cock over each re-agent tank, and a ball-tap over the distributor, which discharges to the bottom of the settling tank through a valve regulated by a float in the settling tank. A trunk conveys the mixed water to the bottom of the settling tank where several baffles are fitted. The upper part of this tank is a filter. The settling tank has a drain cock for the sediment, and the chemical tanks have also drain cocks to remove the impurities of the lime.

Capacity.—600 gallons per hour.

Dimensions.—8 feet long, 4 feet wide, 12 feet 9 inches high. Floor space, 32 square feet.

About sixty of these softeners of various sizes are in use in England and about 2,000 on the Continent.

Working.—The re-agent is alternately prepared in the left or right-hand tank by mixing together the correct amounts of lime, soda and water and stirring these by hand. The re-agent is drawn

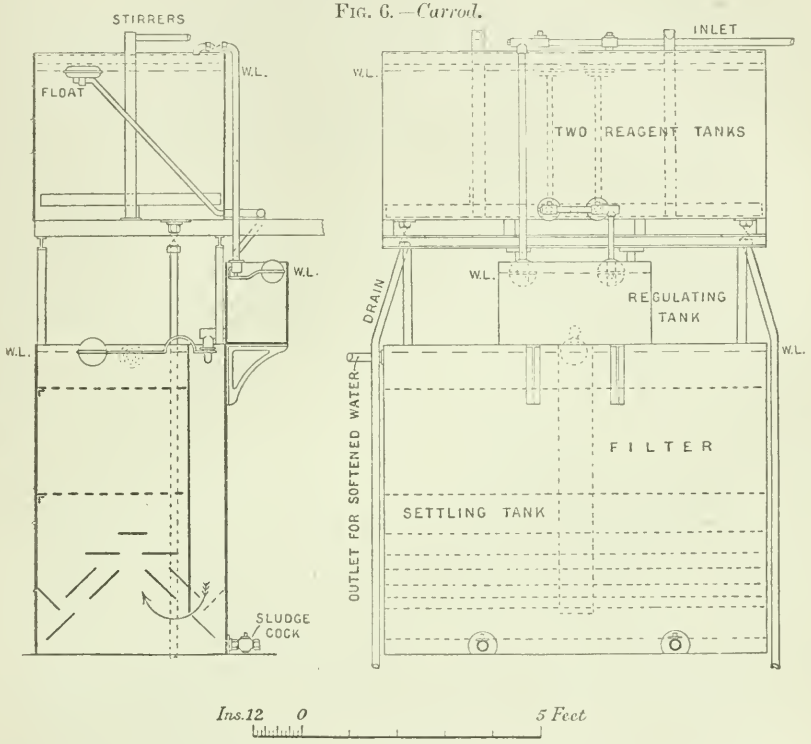


Fig. 6.—*Carrod.*

off near the surface through an india-rubber tube, supported by a float, and passes through a ball-tap into the mixing tank. The untreated water also enters this tank through a ball-tap, and the two quantities should, therefore, always be in a definite ratio. The water is let out of the mixing tank through another ball-tap and descends to the bottom of the settling tank, where baffles arranged in a peculiar manner are intended to assist precipitation. The

precipitate is occasionally drawn off through a cock. The treated water now passes through the filter and thence to the feed-pump. The filtering material, wood-wool, which costs 4*s.* 6*d.* per cwt., is said to last two years.

Supply.—Well water.

Chemicals used.—Caustic soda, quantity not stated.

The users report that the softening (*sic*) is not carried quite so far for the quarry locomotives as for the fixed boiler, because of priming. The effect on the boilers is good, and the brass work or copper fire-boxes are not injured, but the gauge-glass, taps, &c., give more trouble than when ordinary water is used. The sediment from the apparatus is easily removed.

Result of the Chemical Analysis.—This apparatus is designed to use both lime and soda, but waste caustic soda and no lime was used, and the result is that the temporary hardness has been increased 10° and the permanent hardness decreased. This bad result is not due to the apparatus.

DESRUMAUX WATER SOFTENER.

The apparatus, Fig. 7 (page 31), consists of a cylindrical settling tank and a cylindrical lime tank. Over these is placed a distributor and a waterwheel which turns a hollow shaft reaching to the bottom of the lime tank, where several stirrers are attached to it. The same waterwheel also actuates a crank-shaft with a small scoop, which ejects the necessary quantity of soda solution out of the soda tank, which is placed over the settling tank. The settling tank has a central mixing trunk. Attached to the circumference of the settling tank are several screw-shaped inclined plates, the inner edges of which touch the mixing trunk. Higher up is a filter. At the discharge-water level there is a float which controls the water supply. There is also a lime slaking tank over the lime tank.

Capacity.—8,000 gallons per hour, worked at a rate of 5,000 gallons.

Dimensions.—Settling tank, 12 feet 6 inches diameter over angles; lime tank, 4 feet 3 inches over angles. Height of tanks, 34 feet.

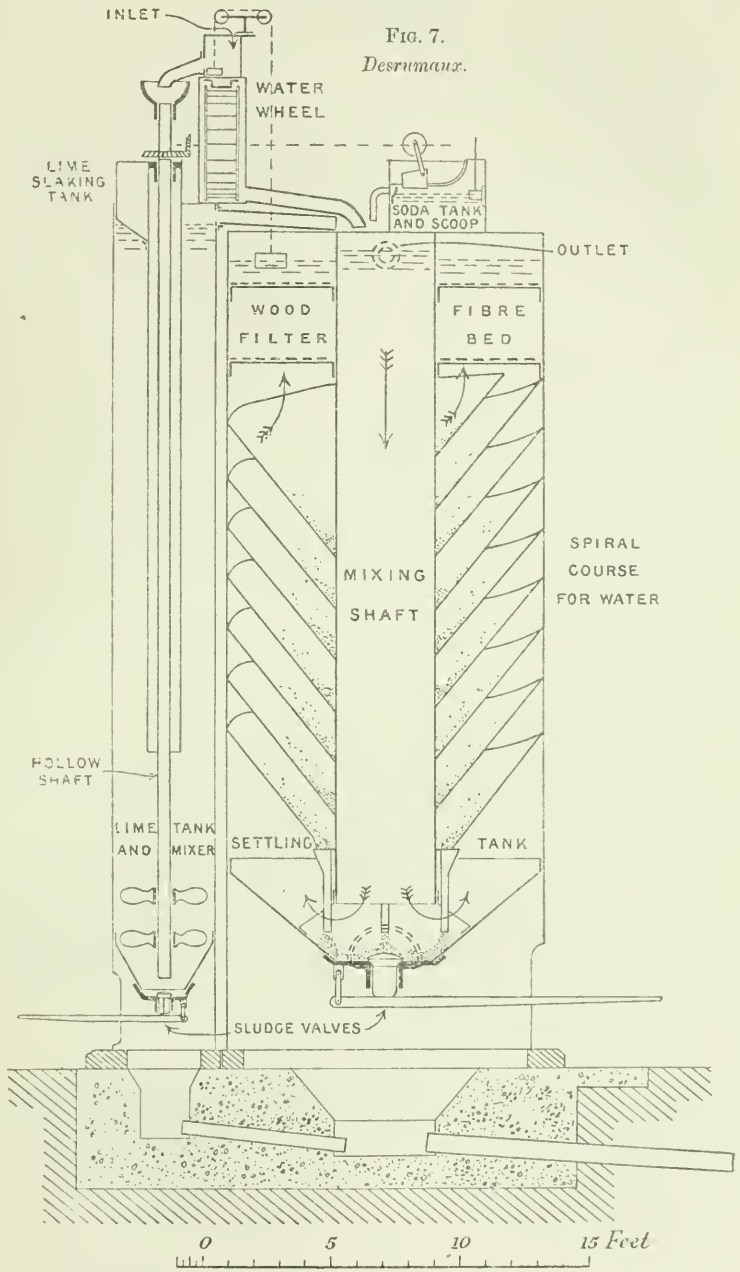


Fig. 7.
Desrumaux.

Total height, 40 feet. Floor space, 16 feet 9 inches by 12 feet 6 inches = 210 square feet.

These softeners are said to be working in all parts of the world.

Working.—The water supply, which is controlled by a float at the delivery, enters the distributor and through two carefully adjusted openings. One stream of water passes through the hollow shaft to the bottom of the lime tank, and gets converted into lime water which overflows into the mixing shaft. The other water stream descends over a water-wheel to the mixing shaft. The water-wheel rotates the stirrers in the lime tower, and also causes the small scoop to throw definite quantities of soda solution into the mixing shaft. The chemical re-action takes place here and the precipitate is formed. The partially cleared water then ascends the settling tank, being carried round and round the helical plates. The sediment which is here formed slips towards the centre and down the steep helical junction line. Before being discharged the water is filtered.

Supply.—Partly town's water, partly brook.

Chemicals used per 1,000 gallons.—2·56 lbs. lime, 0·59 lb. soda.

The analysed water was taken from a reservoir holding 730,000 gallons which was filled in one week, viz. 144 hours, equal to 5,000 gallons an hour.

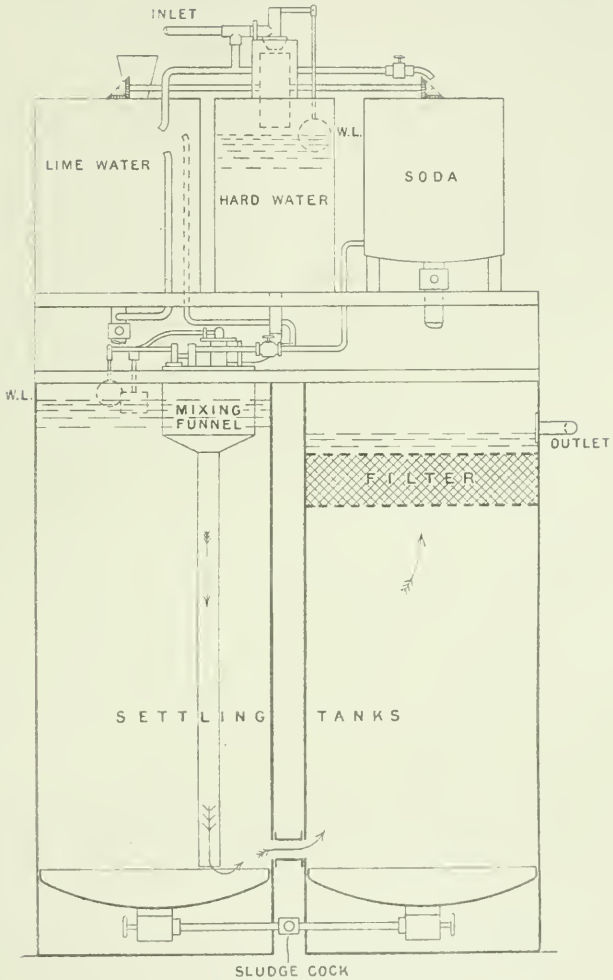
The users report that the apparatus has been giving satisfaction since 1901. The boilers are now opened out only after steaming 1,000 hours, equal to about 4 months at 60 hours per week. Growths of soda appear on the fittings, but the brass is not attacked.

Result of Chemical Analysis.—The supply is the same as that for the Archbutt-Deeley apparatus, but being collected at another time its composition is slightly different. The hardness of the delivery is 4·3° as against 2·3° in the other case. This is chiefly due to a deficiency of the chemicals added.

Doulton Water Softener.

The apparatus, Fig. 8 (page 33), consists of two cylindrical settling tanks with a filter in the upper part of one tank and a mixing funnel and tube in the other. The two tanks are connected near the bottom. Resting on these two tanks are three smaller ones, one for

Fig. 8.—*Doulton.*



Scale, 5 feet = 1 inch.

the milk of lime, one for the untreated water, and one for the soda solution. The lime and the soda tanks have stirrers driven by a water-wheel. Each tank has a pipe leading to the mixing funnel. Above these three tanks is a shaft with a water-wheel and bevel-wheels which actuate the stirrer in the chemical tanks.

Capacity.—4,000 gallons per hour.

Dimensions.—Tank diameters, 6 feet; height of tanks, 14 feet 6 inches. Total height, 24 feet 3 inches. Floor space of tanks, 75 square feet.

About forty-five of these softeners of various sizes are in use.

Working.—Correctly determined quantities of soda and of burnt lime are mixed with hot and cold water respectively, and poured into their tanks. The water supply is then turned on, whereby the water-wheel is rotated and the fluids mixed. The connection from the centre tank to the mixing funnel is now opened, and as the water rises in the mixing tank, the ball-regulator valves of the chemical tanks open, and their contents also pass slowly into the mixing funnel. Should the demand for purified water stop, the water rises in the funnel and causes the three ball-taps to close, and after a time the supply is also cut off automatically over the hard-water tank. Should the water supply be cut off, then, by the sinking of the balls of the taps, the chemical tanks will close automatically. A supply of hard water, regulated by a ball-tap, flows into the lime tank. The sediment which collects in the two settling tanks is run off through two taps. The filtering material is occasionally renewed or washed.

Supply.—Well water.

Chemicals now used are caustic soda and carbonate of soda.

The users report that the water has not yet been used for feeding the boilers. The water does not injure brass fittings. The sponge filters give some trouble, and it is intended to put down two or three settling tanks.

Result of Chemical Analysis.—The water treated by this apparatus was heavily charged with mineral matter, and although the chemical treatment was not correct the temporary hardness has been reduced very low, viz. to 3·1°. The water is, however, very alkaline, due to the excess of soda, but there is no free carbonic acid.

Harris-Anderson Water Softener.*

The apparatus, Fig. 9 (page 37), consists of a distributor, a lime tank, soda tank, air vessel and re-action tank, and settling tank with a filter. The distributor has a circular weir, the water flowing from the circumference to three central compartments, and thence to the air vessel, to the lime tank and to the soda tank respectively. The air vessel, by means of its syphon, acts as an air pump and agitates the milk of lime in the lime tank, in which pipes and cones are arranged for this purpose. The soda tank consists of four cylinders, the solid soda being poured into a cage, the centre one, while the water flows into the second inner cylinder, and, according to the strength of the low-lying soda solution, either passes straight down or overflows into the second cylinder.

Capacity.—1,000 gallons per hour.

Dimensions.—Diameters of the re-action chamber and settling tank are 5 feet 6 inches. The diameter over platform round re-action chamber is $11\frac{3}{4}$ feet. Total height from bottom of settling tank to top of distributor, 17 feet 3 inches. Floor space of platform and settling tank, 158 square feet.

Working.—The water supply passes through a vertical turbine to the circumference of the distributor, thence over the circular weir, whose circumference is properly subdivided, to the air vessel, to the lime tank and to the soda tank. Alternately the water rises and sinks in the air vessel and drives the air into the lime tank, agitating the milk of lime, and then the water in the air tank is syphoned out and the action is repeated. The amount of water added to the lime regulates its supply, and can easily be altered by shifting the subdivision on the circular weir. The central cylinder of the soda tank is filled with soda crystals which partly dissolve in the water, the heavy soda solution settling at the bottom as shown. A small but constant supply of water is run from the distributing weir into the second cylinder, passing through the dense fluid at the bottom and up outside the third cylinder. Should, however, this rising soda solution be very dense, then the added water will flow over the top

* *Engineering*, 10 July 1903, page 52.

of the second cylinder and under the third cylinder. Thus, by adjusting the height of the second inner cylinder, a soda solution of a definite strength is obtained. The sediment formed in the re-action chamber and in the settling tank is run out through a sludge cock.

Supply.—Pit water.

Chemicals used per 1,000 gallons.—2·25 lbs. lime, 2·0 lbs. soda crystals.

The users report that the apparatus works satisfactorily, and that no scale, only mud, is formed in the boiler. The soda solution maintains its strength, but the milk of lime loses about 4 per cent. of its strength per hour.

Result of Chemical Analysis.—The water treated by this apparatus was also heavily charged with mineral matter, and, although an excess of soda was added, the deficiency of added lime resulted in a fairly high temporary hardness, viz. 6·20.

Lassen and Hjort Water Softener (Bruun Lowener).

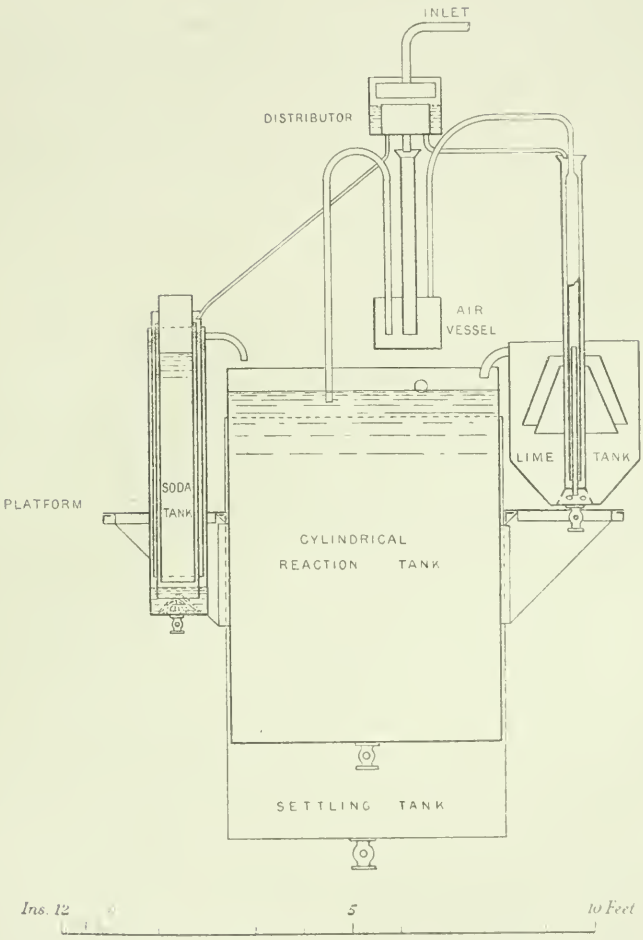
The apparatus, Fig. 10 (page 39), consists of one large tank subdivided into three compartments; a re-action tank, settling tank and filter. Immediately over the re-action chamber is a pivoted double-V-shaped oscillating trough, and above this is a semi-cylindrical chemical tank with stirrer and a valve, both actuated by the oscillating trough. Steam is employed in the re-action chamber for heating and mixing. The untreated water is discharged immediately over the double-V trough, and when one side is full it tips over and empties itself. In doing so a fin, projecting down into the re-action chamber, agitates the mixed water, and a small wheel on the top of the trough knocks against the bottom of a valve spindle and raises it for an instant. The valve is situated in the bottom of the semi-cylindrical chemical tank.

Capacity.—1,000 gallons per hour.

Dimensions.—Length over angle flange, 8 feet 8 inches. Width over angles, 4 feet. Height of tank, 4 feet. Total floor space, 48 square feet.

Working.—The chemicals, about 10 per cent. lime and the necessary soda, are mixed with water, and are poured into the semi-

Fig. 9.—*Harris-Anderson.*



cylindrical tank, and the supply, which is regulated by a ball-tap at the discharge, is turned on, and runs into one of the pivoted V chambers of the oscillating trough. When one side is full, the trough tips over, discharges its water, opens and closes the valve in the bottom of the chemical tank, and by means of blades agitates the chemicals and the mixed water. If no steam is used, the settling tanks have to be larger than shown. The quantity of chemicals discharged through the valve with each tilt of the trough is regulated by the length of the valve rod. The chemicals, assisted by heat from the steam, cause the mineral matter to precipitate in the re-action and settling chamber. The water then passes through the filter to the discharge.

Exhaust steam can be used.

Supply.—No. 1, town's water; No. 2, well water.

Chemicals used per 1,000 gallons.—No. 1, 2 lbs. lime, 1 lb. soda; No. 2, 3·6 lbs. burnt lime, 2·8 lbs. calcined soda.

The users report that this softener works well. There is a little trouble with the valve in the chemical tank, which sticks if the apparatus has been resting for some time. Unless this tank is kept at least half full, the flow of chemicals diminishes.

Result of Chemical Analysis.—Two softeners were dealt with, but only one, referred to as No. 1 in the Analysis Tables (page 57), is illustrated. In this case the proper chemicals were used, and a considerable total hardness has been reduced to a very low limit. No. 2 apparatus dealt with a still harder water, in which the temporary and permanent hardness were about equal, and both have been reduced to nearly the lowest limit, but, a large excess of soda having been added, the alkalinity is high.

Maxim's Water Softener, "Warwick" Detartariser.

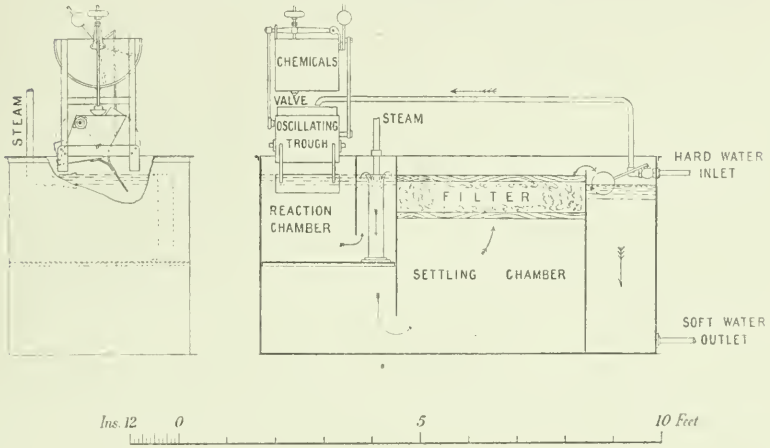
The apparatus, Fig. 11 (page 41), consists of two cylindrical vessels placed one above the other. The untreated water-supply pipe enters the top of the upper vessel and ends in a spraying arrangement, while an exhaust steam-pipe, into which a grease separator is introduced, enters the bottom of the upper vessel. The lower vessel acts partly as a settling tank and partly as a filter.

Capacity.—3,000 gallons per hour.

Dimensions.—Diameter of lower cylinder over angles, 7 feet 6 inches. Total height, exclusive of sludge cocks and exhaust pipe, 24 feet. Floor space, exclusive of grease separator, is 56 square feet.

Working.—The hard water enters the upper chamber through a valve which is regulated by a float on the discharge. The necessary amount of soda solution is injected into this water by means of a pump connected to the feed. This water comes in contact with exhaust steam from the engine, from which most of the grease has

Fig. 10.—*Lassen and Hjort.* (No. 1.)



already been removed by a grease separator. The water thereby acquires a temperature of about 212° Fahr. The condensed steam is added to it and it then falls into the lower tank. The heat and the soda cause the mineral matter to be precipitated, and the grease adheres to the sediment. As a safeguard a filter is fitted. The sludge is occasionally run out of the cocks in the lower tank.

Supply.—Pit water.

Chemicals used.—Soda, quantity not stated.

The users report that they are well pleased with the softener, and now have two at work. Partly because the boilers are now free from

scale, partly because their feed is now heated to 200° F., the softeners have paid for themselves in 12 months' time.

Result of Chemical Analysis.—The analysis shows that only 6 to 11 per cent. condensed steam were added to the supply. By subtracting 6 per cent. of pure water, the values in the third column of the Table of Analysis (page 58) are obtained. It will be seen that the slightly deficient carbonate of soda has converted nearly all the permanent hardness into temporary hardness, and that the small quantity of steam combined with a probably low temperature had no power to drive off the carbonic acid, which now held nearly 26 grains of carbonate of lime and magnesia in solution. Caustic lime or caustic soda ought to have been added to this water.

PORTER-CLARK WATER SOFTENER.

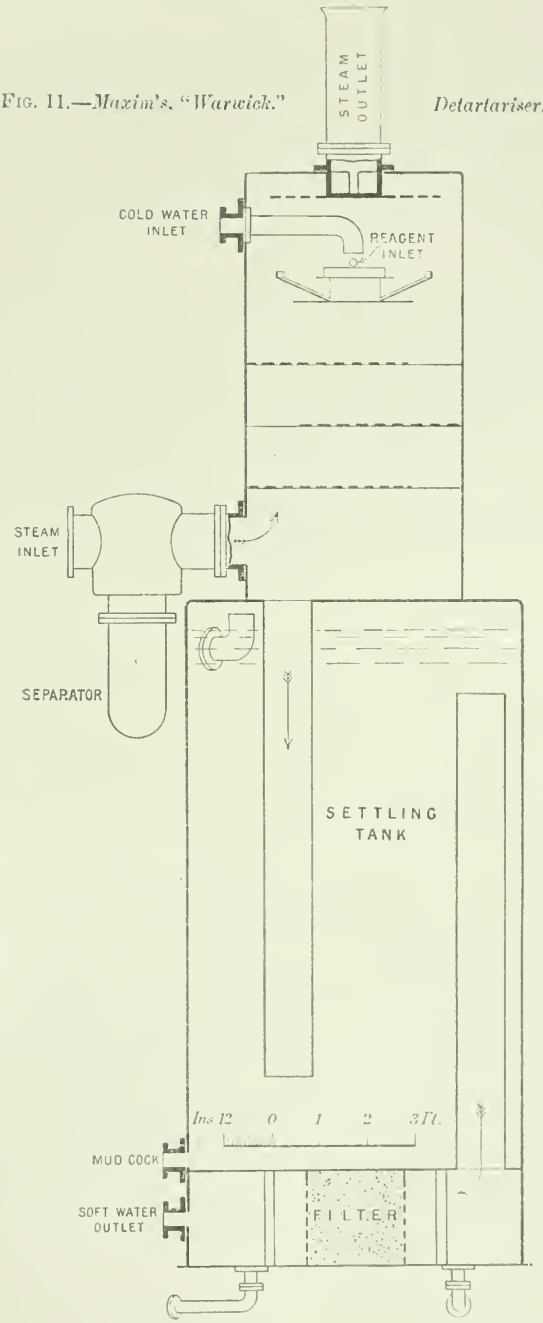
The apparatus, Fig. 12 (page 43), consists of several tanks placed side by side. The surface heater fitted at these works is not an essential feature of the softener. At the right-hand corner is the lime tank, next to it is the soda tank. The large tank is subdivided into a mixing tank, a settling tank, and next to it are the cloth filters. An engine-driven shaft passes over the lime, soda and mixing tank, and by means of bevel wheels actuates the stirrers. It also drives two small iron pumps which draw from the chemical tanks. The lime solution discharge is near the inlet of the untreated water. The soda discharge is at the outlet of the mixing tank. There is a collecting trough at one end of the settling tank, and adjoining it are eighteen cloth filters.

Capacity.—3,000 gallons per hour.

Dimensions.—Lime mixer, 4 feet 9 inches square, 5 feet high. Soda tank, 3 feet by 2 feet by 3 feet high. Mixing tank and settling tank, 10 feet by 6 feet by 5 feet high. Filter, 10 feet by 5 feet by 5 feet high. Floor space, 152 square feet. Heater, 3 feet diameter, 21 feet long.

Working.—The water, after passing the surface heater, enters the mixing tank, where it gets mixed with milk of lime which is pumped

FIG. 11.—*Maxim's "Warwick." Detartariser.*



into this tank in the correct proportion. The partly treated water while flowing out of this tank is mixed with a regulated quantity of soda solution and slowly passes along the settling tank where most of the precipitate is deposited. It then overflows into a distributing tank, and thence on to the cloth filters and to the feed pump.

Supply.—Not stated.

Chemical used per 1,000 gallons, 7 lbs. lime putty and 1·5 lb. soda crystals.

The users report that the water was intended more for washing purposes than for boilers, in these some pitting was noticed. Subsequently the softener was replaced by another patent.

Result of Chemical Analysis.—In this case the supply had much temporary and permanent hardness, but as only half the necessary quantity of soda was introduced the result was naturally very unsatisfactory, and it is impossible to judge how the apparatus would have acted if properly worked.

PULSOMETER WATER SOFTENER. CRITON.

Working.—Details from which to make a sketch of this softener were not obtainable, for this company have redesigned their softener since the samples were analysed. The flow of the water and chemicals was regulated by syphon and ball-taps.

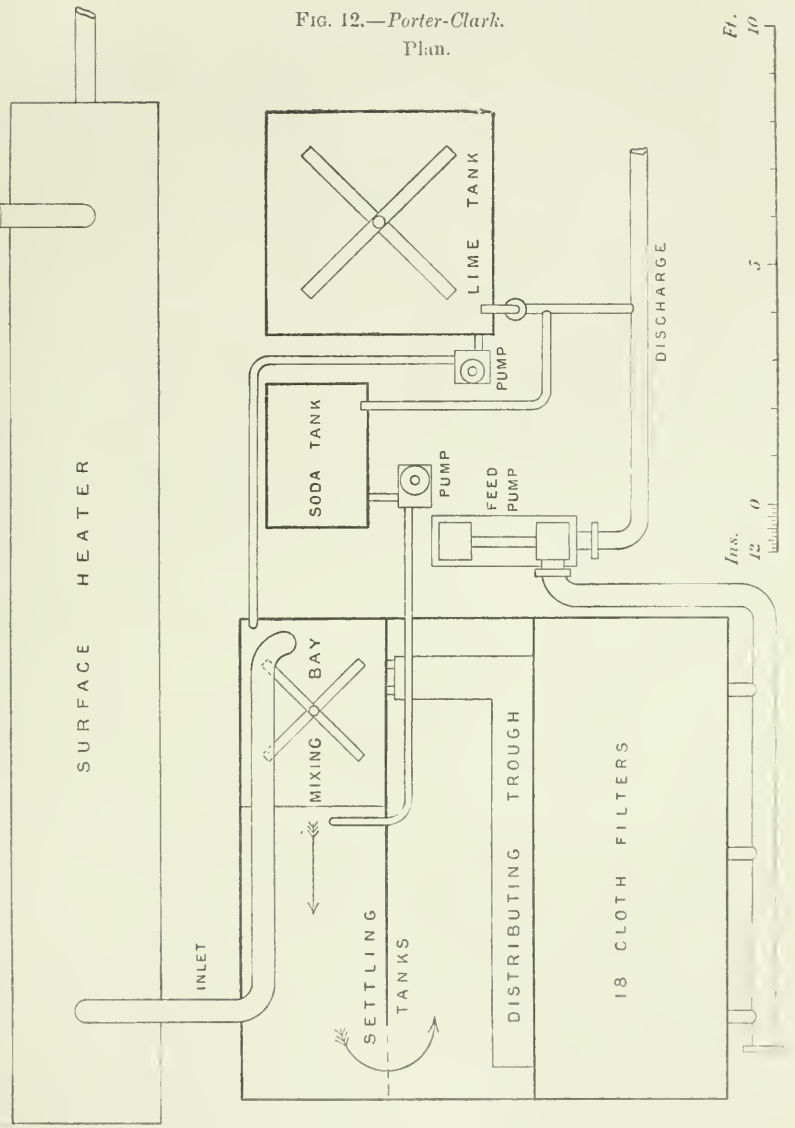
Supply.—Well water.

Chemicals used.—Lime, but the quantity is not stated.

The users were apparently not aware that they had no permanent hardness in their supply, and they report that they formerly added soda; this naturally caused their boiler fittings to give trouble, which has now ceased. No scale, only mud, is formed in the boiler.

Result of Chemical Analysis.—The water treated was alkaline and had no permanent hardness. No soda was, therefore, added. Unfortunately an excess of lime was used, which produced 2 grains of caustic soda, and which accounts for the resultant high temporary hardness and high alkalinity. An addition of water having permanent hardness would have improved the product.

Fig. 12.—*Porter-Clark.*
Plan.



REISERT WATER SOFTENER. TYPE E.

The apparatus, Fig. 13 (page 45), consists of a large settling tank and filter combined, over which is placed a distributor. In addition there is a conical lime tank and a cylindrical soda tank. Pipes with carefully gauged apertures lead the water from the distributor to the top of the soda tank and to the bottom of the lime tank and to the bottom of the settling tank. A syphon from the soda tank and an overflow from the lime tank are also led into the bottom of the re-action tank. A pipe passes from the supply under the filter for automatically washing away the precipitate on the filter when the resistance is increased so much as to raise the water level. The mud in the settling tank is drawn off through a sludge cock.

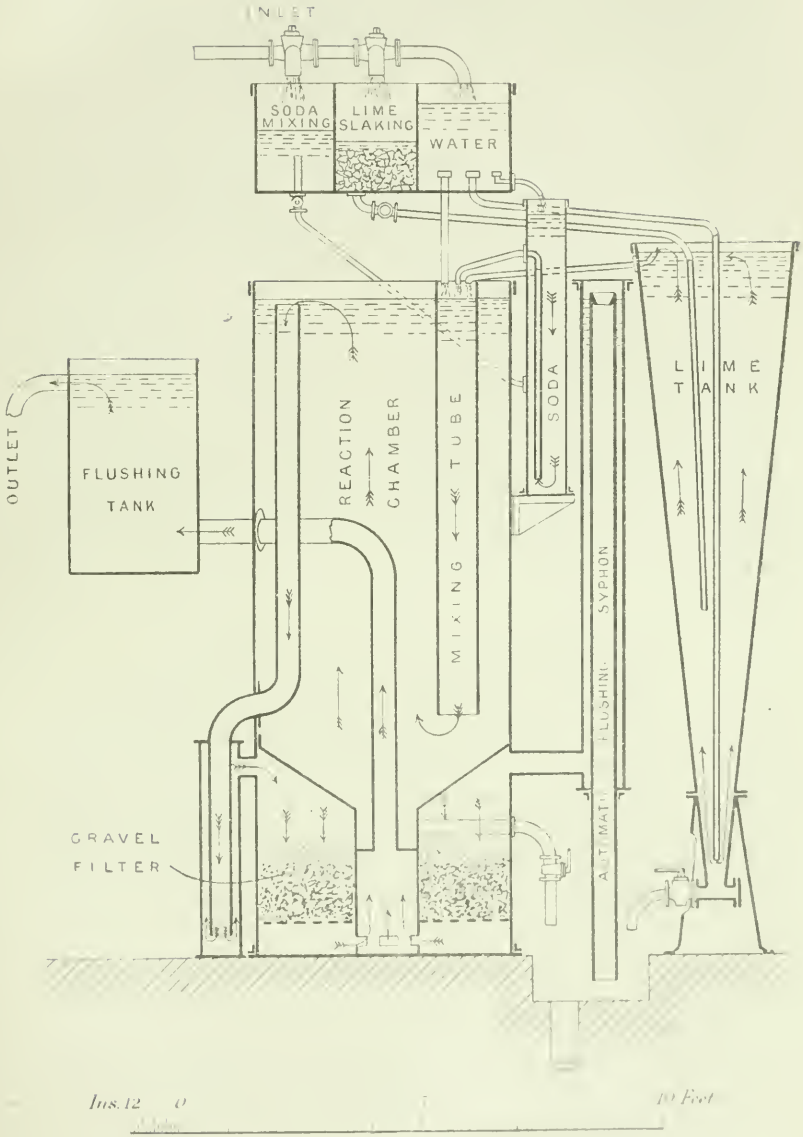
Capacity.—1,300 gallons per hour.

Dimensions.—Settling tank, 5 feet 3 inches diameter. Lime tank, 3 feet 9 inches diameter at top to 6 inches at bottom. Total height, 22 feet 6 inches. Floor space, 41 square feet.

About 2,000 of these softeners of various sizes are said to be in use on the Continent.

Working.—The correct quantity of lime is placed in a small tank, slaked and converted into milk of lime, which is then run into the bottom of the conical lime tank. The right quantity of soda and water is placed in the cylindrical soda tank and steam is turned on until the soda is dissolved and the contents of the tank well mixed and of uniform density. The water supply, which has been temporarily stopped, is now re-started, and passes from the distributor through three carefully gauged holes. One portion goes direct to the bottom of the settling tank into a little mixing chamber. Another portion flows to the bottom of the lime tank, the same quantity of concentrated lime water flowing off the top of this tank into the mixing chamber. The third portion of water is led to the top of the soda tank, and being lighter than the soda solution it floats on its surface, and by depressing it, causes it to rise up the syphon pipe to the mixing chamber. The three fluids being well mixed precipitation takes place, the sludge settling in the bottom of the settling tank and being drawn off occasionally. The partly clarified water passes

Fig. 13.—*Reisert.*



through a pipe to the bottom of the gravel filter where the remaining precipitate is removed and the purified water then passes to the feed-pump. The filter is occasionally cleaned by an automatic reversal of the flow, whenever the filter is fouled. The mud passes down the waste pipe.

Supply.—Well water.

Chemicals used per 1,000 gallons, 2·7 lbs. lime and 1·4 lb. soda.

The users report that the apparatus has worked satisfactorily for two and a half years, and the boilers have given no trouble. It takes one man half-an-hour every twelve hours to charge the chemicals.

Result of Chemical Analysis.—This is one of the few softeners in which an excess of lime was added, with the result that nearly all the magnesia has been removed, but the excess of lime has also caused the temporary hardness to be fairly high, namely 4·4°. The treated water also shows 3·5° of permanent hardness, which could have been entirely removed if enough soda had been added. This insufficiency of soda is probably partly due to the presence of sulphate of lime as an impurity in the burnt lime.

Stanhope Continuous Water Softener.

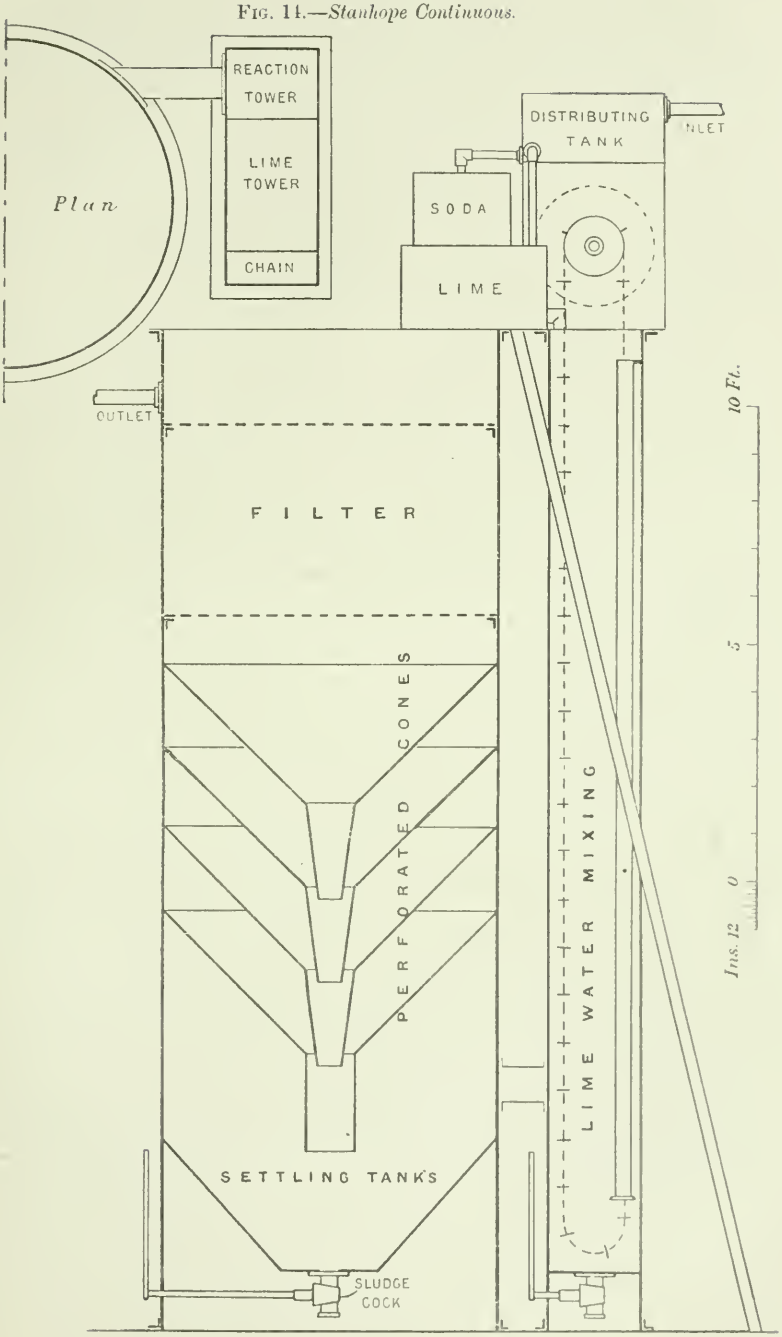
The apparatus, Fig. 14 (page 47), consists of a lime-mixing tank, with a small compartment for the mixing chain, a re-action tank and a settling tank with inverted perforated funnels and a filter. Above these cylindrical tanks is a distributor, a soda tank and a lime-slaking tank. The distributor has three carefully adjusted outlets, one discharging into the re-action tank, and one into the lime tank and another into the soda tank. The chain in the lime mixing tank is driven by a water wheel.

Capacity.—2,500 gallons per hour, but worked at 1,000 gallons per hour.

Dimensions.—Settling tank, 7 feet 6 inches diameter over angles. Re-action and settling tower, 5 feet 6 inches by 2 feet 6 inches over angles. Height, 26 feet. Floor space, 70 square feet.

About ninety of these softeners of various sizes are in use.

FIG. 14.—*Stanhope Continuous.*



Working.—The water enters the distributor, the supply being regulated by a ball-tap at the discharge. Three carefully gauged outlets lead this water respectively into the mixing tank, into the lime-mixing tank and into the soda tank. The slaking of the lime is done in a separate tank. The re-action between the lime, soda and untreated water takes place at the same time. The treated water passes upwards through perforations in the cones and then through the filter. The sludge falls down through the openings in the centre of the cones and is run out of the sludge cock.

Supply.—Town's water.

Chemicals used per 1,000 gallons, 0·5 lb. lime, 0·5 lb. soda crystals.

The users report that the sediment in the softener is easily removed. The filters are cleared twice a year, which takes about two days. Hardness of treated water varies from 2° to 4·5°.

Result of Chemical Analysis.—Insufficient lime and soda were added, but as the water contained little magnesia salts, the result was a good one, the combined hardness being reduced to 2·6°.

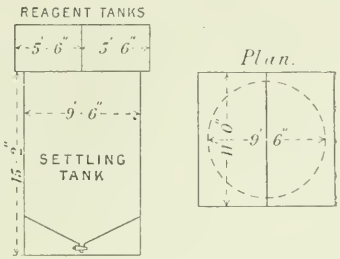
Tyacke Water Softener.

Working.—The apparatus, Fig. 15 (page 49), consists of a cylindrical settling tank with a central funnel and mixing tank. It has a sludge cock at the bottom. Above the funnel are two regulating tanks with ball-taps; above them are two chemical tanks with floating discharge pipes. Only one tank is used at a time. Sufficient lime and water to produce clear lime water is put alternately into one of the two chemical tanks, the fluid is drawn off through a floating discharge, the quantity being regulated by a ball-tap in a lower tank. The water to be treated is discharged into a similar tank with a ball-tap, and the mixture passes to the bottom of a settling tank and is drawn off at the surface. The apparatus has been in use since 1894.

Result of Chemical Analysis.—This apparatus was supplied with the hardest of the waters submitted, there being 55° permanent hardness and 21° temporary hardness. Unfortunately far too little lime was added, so that the 18 grains of magnesium salts were

hardly reduced at all. Only half the necessary quantity of soda was added, and the general result was most unsatisfactory. It is impossible to judge from this case how the apparatus would have behaved with less difficult water and if the chemicals had been properly proportioned.

Fig. 15.—*Tyacke.*



Wollaston Water Softener.

The apparatus, Fig. 16 (page 51), consists of a settling tank and a re-action tank, surmounted by a feed-heater with numerous trays. The inlet for the chemicals is at the bottom of this heater, from which a pipe shown in dotted lines leads to the bottom of the first re-action tank. An external overflow pipe leads from this tank to the bottom of the settling tank, which is provided with settling planes. The pump for the chemicals is actuated by the feed-pump.

Capacity.—4,000 gallons per hour.

Dimensions.—Re-action tank, 3 feet 4 inches diameter over angles. Settling tank, 5 feet 5 inches by 10 feet 5 inches; height, 13 feet. Feed-heater, 2 feet 7 inches diameter, 8 feet high. Floor space, 66 square feet.

About fifteen of these softeners of various sizes are in use.

Working.—The water is admitted at the top of the feed-heater, exhaust steam which has passed through a grease separator being blown into the bottom. The descending water passes over several trays and then meets with a stream of soda solution which completes the re-action initiated by the heat of the steam. The grease and precipitated lime adhere to each other and mutually increase their

tendency to separate from the water. Most of the precipitate remains in the re-action tank, and only a small quantity is carried into the settling tank. No filter was used.

Supply.—Well water.

Chemicals used.—Caustic soda, quantity not stated.

The users report that the effect on the boiler is satisfactory except that old scale is not loosened. With recent installations, in which there is no excess of alkalinity, the old scale is rapidly coming away, even from within the Makin's boiler cones.

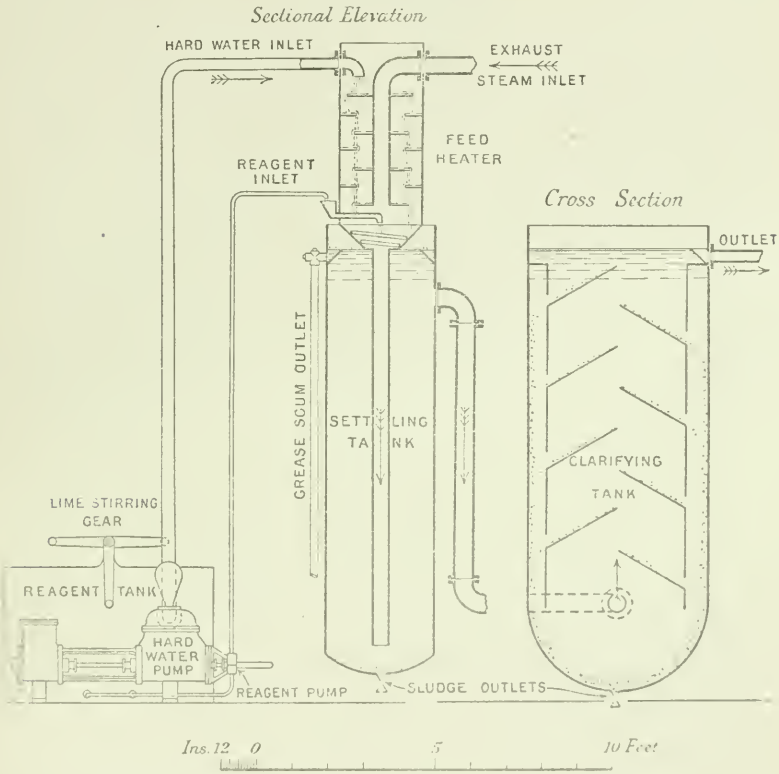
Result of Chemical Analysis.—The analysis shows that about 33 per cent. of condensed steam was added to the supply which has to be subtracted from the delivery. This has been done in the third column of Table of Analysis (page 61), where it will be seen that a total hardness of 20·5° had been reduced to 0·86°, but the alkalinity of the treated water is so high, due to 18 grains of carbonate of soda, that one might expect that the concentrated boiler water would attack the brass fittings. The users make no complaint on this subject. At these works waste caustic soda from the mercerisers was available, of which an excess of 2 lbs. per 1,000 gallons was used. It would have been better to use only 0·809 lb. of caustic soda and 1·076 lbs. of lime. The lime would have dealt with 13° of temporary hardness, and the caustic soda, after combining with the carbonic acids, would have dealt with the permanent hardness, and practically no carbonate of soda would have been found in the delivery.

WRIGHT WATER SOFTENER.

The apparatus, Fig. 17 (page 52), consists of a rectangular settling tank, filter, mixing tank, and lime tank combined, surmounted by a distributor. At the side of the lime tank is a lime-slaking tank and a soda tank, not shown. The settling tank has a large number of 6-inch baffle plates, inclined at an angle of 45°, on which the mud settles and slips down. Above these baffles is a filter, and at the discharge level is a float attached to a leather hose in the distributor, which causes the two water levels to rise and fall together. Another float in the distributor regulates the supply of unsoftened water.

This arrangement has been superseded. The distributor has a weir with two adjustable overflows to the mixing tank and lime tank. A mixing chain reaches to the bottom of the lime tank and a small bucket chain draws from the soda tank. These chains are actuated by a water-wheel.

Fig. 16.—*Wollaston.*

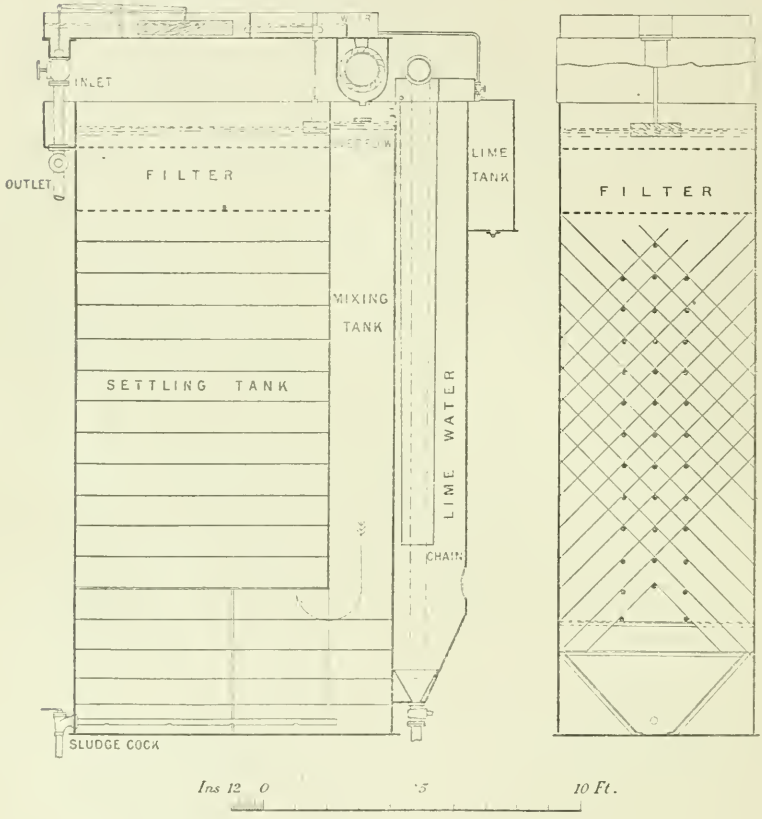


Capacity.—10,000 gallons per hour, but only worked up to 5,000 gallons.

Dimensions.—Combined tank, not including lime-slaking tank and platform, 6 feet 5 inches wide 13 feet 6 inches long, 23 feet high.

In addition there are two cylindrical settling tanks, not shown, 7 feet 6 inches diameter, 27 feet high. Floor space of apparatus, 86 square feet; ditto, including two tanks, 112 square feet.

Fig. 17.—*Wright.*



This firm also make water softeners in which exhaust steam is utilised.

Working.—The untreated water flows over a weir, one part descending over a water-wheel direct into the mixing tank, the other part passes to the bottom of the lime tower, forcing the same

quantity of clear lime water into the mixing tank. A small, but definite, quantity of soda solution is also tipped into the mixing tank, the bucket chain being actuated by the water-wheel. From the bottom of the mixing tank the mixed water passes up through the settling tank, most of the mud settling on the large number of baffles and slipping down. It is now and then removed through the sludge cock. The mud which gets arrested at the bottom side of the filter is easily washed into the settling tank by opening the sludge cock.

The users report that the boilers are fed partly by softened, partly by unsoftened, water, and the effect on the boilers has not been noted. The baffle plates were cleaned twice in twelve years. Half the filter stockings are changed every day. The mud is easily run off. There used to be a deposit in the pipes, now two boiler shells, 27 feet high by 7 feet 6 inches diameter, are used as extra settling tanks.

Result of Chemical Analysis.—The water treated by this apparatus presented no serious difficulties, but here again the mistake was made of adding too little lime and too much soda, and although the delivery is fairly soft its alkalinity is rather high.

(*Continued on opposite page.*)

APPENDIX III.

Chemical Analysis.

Name of Water Softener.				Archbutt-Deeley.		The Atkins Co.	
Chemicals, &c.			Chemical Symbols.	Supply.	Delivery.	Supply.	Delivery.
				Grains per Gallon.			
Carbonic Acid Gas.			CO_2	7·161	0·63	6·795	1·27
Scale-forming Constituents.	Calcium	Sulphate	$Ca SO_4$	2·639	0·000	0·715	0·715
		Carbonate	$Ca CO_3$	6·659	1·704	13·909	1·709
		Silicate	$Ca Si O_3$	1·733	1·175	1·110	1·030
	Magnesium.	Hydrate	$Mg (OH)_2$	—	—	—	—
		Carbonate	$Mg CO_3$	5·418	0·073	—	—
		Silicate	$Mg Si O_3$	—	—	—	—
	Ferric Oxide			0·330	0·148	0·024	0·017
	Total			16·779	3·100	15·758	3·471
Non-Scale-forming Constituents.	Sodium.	Nitrate	$Na NO_3$	—	—	0·716	0·738
		Chloride	$Na Cl$	2·675	3·211	2·881	2·939
		Sulphate	$Na_2 SO_4$	0·000	5·402	—	—
		Carbonate	$Na_2 CO_3$	—	—	—	—
		Bi-Carbonate	$Na H CO_3$	0·000	1·401	—	—
		Silicate	$Na_2 Si O_3$	—	—	—	—
		Hydrate	$Na HO$	—	—	—	—
	Calcium.	Nitrate	$(Ca NO_3)_2$	—	—	2·903	2·882
		Chloride	$Ca Cl_2$	—	—	—	—
	Magnesium.	Nitrate	$Mg (NO_3)_2$	—	—	0·904	0·904
		Chloride	$Mg Cl_2$	0·251	0·000	—	—
		Sulphate	$Mg SO_4$	—	—	—	—
	Totals			2·926	9·814	7·404	8·463
Total Mineral Matter . . .				19·705	12·914	23·162	11·934
Alkalinity				14·582	3·632	14·680	2·320
Temporary Hardness . . .				14·582	2·799	14·680	2·320
Permanent Hardness . . .				2·203	0·000	3·165	3·165
Total Hardness				16·785	2·799	17·845	5·485
Chemicals required in pounds per 1,000 gallons.*							
Lime			Ca O	1·90	- 0·60	1·305	0·28
Soda			$Na_2 CO_3$	0·35	- 0·25	0·44	0·44
Cost per 1,000 gallons . .			Pence	0·41	—	0·399	—

* The minus sign (-) stands for excess.

ANALYSES.

(*Continued on next page.*)

Chemical Analysis.

Babcock and Wilcox.			Bell.		Boby.		
Supply.	Delivery.	Delivery less Steam.	Supply.	Delivery.	Supply.	Delivery.	Delivery less Steam
Grains per Gallon.							
3·940	4·070	—	2·39	3·22	10·36	1·40	—
8·001	0·000	0·000	29·918	0·000	17·126	4·532	5·734
2·549	6·319	9·972	0·000	1·706	17·271	0·205	0·259
2·615	1·184	1·868	—	—	2·176	1·560	1·974
—	—	—	—	—	—	—	—
3·339	1·365	2·154	3·619	3·598	2·966	1·768	2·237
—	—	—	0·913	0·800	—	—	—
0·611	0·008	0·013	0·008	0·005	0·044	0·011	0·014
17·115	8·876	14·007	34·458	6·109	39·583	8·076	10·218
—	—	—	—	—	—	—	—
16·676	10·612	16·745	8·690	8·669	5·423	4·739	5·995
32·736	26·045	41·100	12·491	56·700	1·157	10·322	13·059
—	—	—	—	—	—	—	—
0·000	11·923	18·815	0·000	9·844	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	10·662	0·000	—	—	—
49·412	48·580	76·660	31·843	75·213	6·580	15·061	19·054
66·527	57·456	90·667	66·301	81·322	46·163	23·137	29·272
8·757	16·050	28·960	5·199	12·628	22·661	3·612	4·606
8·757	8·954	14·131	5·199	6·770	22·661	3·612	4·606
5·883	0·000	0·000	30·858	0·000	12·590	3·332	4·216
14·640	8·954	14·131	36·057	6·770	35·251	6·974	8·822
Chemicals required in pounds per 1,000 gallons.*							
1·034	0·000	—	1·599	1·459	2·166	0·000	—
0·892	- 1·075	—	4·676	- 0·888	1·908	0·500	—
0·635	—	—	2·922	—	1·354	—	—

* The minus sign (-) stands for excess.

(*Continued from previous page.*)

APPENDIX III.

Chemical Analysis.

Name of Water Softener.				Carrod.		Desrumaux.	
Chemicals, &c.			Chemical Symbols.	Supply.	Delivery.	Supply.	Delivery.
				Grains per Gallon.			
Carbonic Acid Gas.			CO_2	6·21	1·14	5·83	1·25
Scale-forming Constituents.	Calcium.	Sulphate	$Ca\,SO_4$	33·105	3·430	2·963	0·635
		Carbonate	$Ca\,CO_3$	0·000	4·780	5·990	1·485
		Silicate	$Ca\,Si\,O_3$	2·893	3·902	1·909	0·163
	Magnesium.	Hydrate	$Mg\,(OH)_2$	—	—	—	—
		Carbonate	$Mg\,CO_3$	10·999	14·562	5·115	1·873
		Silicate	$Mg\,Si\,O_3$	—	—	—	—
	Ferric Oxide			0·113	0·155	0·063	0·059
	Total . . .			47·110	26·829	16·040	4·215
Non-Scale-forming Constituents.	Sodium.	Nitrate	$Na\,NO_3$	—	—	—	—
		Chloride	$Na\,Cl$	3·380	3·671	2·818	3·606
		Sulphate	$Na_2\,SO_4$	5·449	38·528	0·000	3·156
		Carbonate	$Na_2\,CO_3$	—	—	—	—
		Bi-Carbonate	$Na\,H\,CO_3$	—	—	—	—
		Silicate	$Na_2\,Si\,O_3$	—	—	—	—
		Hydrate	$Na\,HO$	—	—	—	—
	Calcium.	Nitrate	$Ca\,(NO_3)_2$	—	—	—	—
		Chloride	$Ca\,Cl_2$	—	—	—	—
	Magnesium.	Nitrate	$Mg\,(NO_3)_2$	—	—	—	—
		Chloride	$Mg\,Cl_2$	—	—	0·228	0·000
		Sulphate	$Mg\,SO_4$	1·204	0·000	—	—
	Totals . . .			10·033	42·199	3·046	6·762
Total Mineral Matter.				57·143	69·028	19·086	10·977
Alkalinity				15·54	25·410	13·701	3·847
Temporary Hardness				15·54	25·410	13·701	3·847
Permanent Hardness				25·34	2·522	2·419	0·467
Total Hardness				40·88	27·932	16·120	4·314
Chemicals required in pounds per 1,000 gallons.*							
Lime			$Ca\,O$	2·25	1·59	1·563	0·406
Soda-Ash			$Na_2\,CO_3$	3·84	0·37	0·367	0·070
Cost per 1,000 gallons . .			Pence	2 5	—	0·383	—

* The minus sign (-) stands for excess.

ANALYSES.

(*Continued on next page.*)

Chemical Analysis.

Doulton.		Harris-Anderson.		Lassen and Hjort. (1)		Lassen and Hjort. (2)	
Supply.	Delivery.	Supply.	Delivery.	Supply.	Delivery.	Supply.	Delivery.
Grains per Gallon.							
4·78	0·00	8·856	0·000	6·84	1·39	10·000	1·87
22·772	0·00	18·680	0·000	1·99	—	20·472	0·000
12·305	0·814	6·53	1·938	14·701	1·009	5·588	0·311
—	—			2·308	1·951	1·338	0·000
—	—	0·291	0·000	—	—	—	—
0·000	1·896	9·177	3·235	0·000	0·365	13·110	2·841
—	—	—	—	—	—	—	0·398
0 147	0·112	0·244	0·111	0·017	0·091	0·067	0·047
35·224	2·822	34·571	5·575	18·116	3·416	40·575	3·597
0·000	25·932	—	—	—	—	—	—
8·238	10·755	23·971	23·971	1·145	3·161	4·586	8·887
0·000	26·462	30·717	49·462	0·000	1·881	0·000	19·980
0·000	13·921	0·000	0·671	—	—	—	—
0·000	30·502	—	—	0·000	1·783	0·000	19·128
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
14·626	0·000	—	—	—	—	—	—
—	—	—	—	0·707	0·000	—	—
9·380	0·000	—	—	—	—	—	—
1·177	0·000	—	—	0·803	0·000	2·961	0·000
—	—	—	—	—	—	—	—
33·421	107·572	54·688	74·104	2·655	6·825	7·547	47·995
68·645	110 394	89·259	79·679	21·671	10·241	48·122	51·592
12·303	34·33	17·350	6 907	16·685	4·179	22·297	15·459
12·303	3·064	17·350	6·275	16·685	3·118	22·297	4·077
33·215	0·000	13·731	0·000	2·945	0·000	18·160	0·000
45·518	3·064	31·081	6·275	19·630	3·118	40·457	4·077
* Chemicals required in pounds per thousand gallons.							
1·5	1·5	2·476	0·312	1·31	0·000	3·31	1·56
5·0	- 4·274	2·081	- 0·035	0·44	- 0·16	2·75	- 1·69
3·11	—	1·475	—	0·4	—	1·935	—

* The minus sign (-) stands for excess.

(*Continued from previous page.*)

APPENDIX III.

Chemical Analysis.

Name of Water Softener.				Maxim.		
Chemicals, &c.			Chemical Symbols.	Supply.	Delivery.	Delivery less Steam.
				Grains per Gallon.		
Carbonic Acid Gas			CO_2	6·33	5·67	—
Scale-forming Constituents.	Calcium	Sulphate	$Ca\,SO_4$	38·600	4·746	5·058
		Carbonate	$Ca\,CO_3$	0·000	10·149	12·368
		Silicate	$Ca\,Si\,O_3$	0·984	1·170	1·247
	Magnesium	Hydrate	$Mg\,(OH)_2$	—	—	—
		Carbonate	$Mg\,CO_3$	12·032	15·333	16·340
		Silicate	$Mg\,Si\,O_3$	—	—	—
	Ferric Oxide			0·367	0·112	0·119
	Total			51·983	31·510	35·132
Non-Scale-forming Constituents.	Sodium	Nitrate	$Na\,NO_3$	—	—	—
		Chloride	$Na\,Cl$	130·790	117·05	124·740
		Sulphate	$Na_2\,SO_4$	14·743	55·772	59·382
		Carbonate	$Na_2\,CO_3$	—	—	—
		Bi-Carbonate	$NaH\,CO_3$	—	—	—
		Silicate	$Na_2\,Si\,O_3$	—	—	—
		Hydrate	$Na\,HO$	—	—	—
	Calcium	Nitrate	$Ca\,(NO_3)_2$	—	—	—
		Chloride	$Ca\,Cl_2$	—	—	—
	Magnesium	Nitrate	$Mg\,(NO_3)_2$	—	—	—
		Chloride	$Mg\,Cl_2$	—	—	—
		Sulphate	$Mg\,SO_4$	8·122	0·000	0·000
	Total			153·655	172·772	184·122
Total Mineral Matter . . .				205·635	204·282	219·254
Alkalinity				15·128	29·346	31·276
Temporary Hardness				15·128	29·346	31·276
Permanent Hardness				35·128	3·490	3·719
Total Hardness				50·256	32 836	34·995
Chemicals required in pounds per 1,000 gallons.*						
Lime			$Ca\,O$	2·834	2·486	—
Soda-Ash			$Na_2\,CO_3$	5·323	0·529	—
Cost per 1,000 gallons . . .			Pence	3·44	—	—

* The minus sign (-) stands for excess.

ANALYSES.

(*Continued on next page.*)

Chemical Analysis.

Porter-Clark.		Pulsometer.		Reisert.		Stanhope.	
Supply.	Delivery.	Supply.	Delivery.	Supply	Delivery.	Supply.	Delivery.
Grains per Gallon.							
5·03	0·13	5·54	0·00	6·68	0·000	5·70	0·32
12·178	10·074	—	—	4·696	4·762	4·084	1·192
8·971	9·000	5·193	1·551	10·123	1·456	1·259	0·516
1·694	0·493	3·671	2·541	2·050	1·355	1·371	1·184
—	—	0·000	0·376	0·000	0·284	—	—
0·109	0·918	4·270	0·000	1·453	0·000	0·049	0·938
—	—	—	—	—	0·737†	—	—
0·246	0·057	0·047	0·034	0·251	0·054	0·082	0·036
23·198	11·542	13·181	4·502	18·873	8·617	6·845	3·866
0·000	12·261	—	—	0·106	6·247	—	—
5·463	5·576	10·556	11·037	3·750	3·773	1·443	2·801
0·000	1·933	8·729	7·186	0·000	0·943	0·00	2·743
—	—	0·000	3·484	—	—	—	—
—	—	7·336	0·000	—	—	—	—
—	—	—	—	—	—	—	—
—	—	0·000	2·158	—	—	—	—
—	—	—	—	5·003	0·000	—	—
—	—	—	—	—	—	—	—
12·309	1·621	—	—	—	—	—	—
—	—	—	—	—	—	1·010	0·00
—	—	—	—	—	—	—	—
17·772	21·391	26·621	23·865	8·859	10·963	2·453	5·544
40·970	32·933	39·802	28·367	27·732	19·610	9·298	9·410
11·432	1·512	17·780	10·356	13·910	3·501	13·830	2·656
11·432	1·512	13·416	4·379	13·910	3·501	13·830	2·656
17·248	8·498	0·000	0·000	6·502	4·421	4·063	0·867
28·68	10·01	13 416	4·379	20·412	7·925	17·893	3·523
Chemicals required in pounds per 1,000 gallons.*							
1·658	0·253	1·412	- 0·218	1·353	- 0·105	1·127	0·146
2·614	1·288	—	—	0·985	0·530	0·616	0·132
1·71	—	0·15	—	—	—	0·49	—

* The minus sign (-) stands for excess. † (Reisert delivery) calcium oxide, Ca O.

(*Continued from previous page.*)

APPENDIX III.

Chemical Analysis.

Name of Water Softener.			Tyacke.	
Chemicals, &c.		Chemical Symbols.	Supply.	Delivery.
			Grains per Gallon.	
Carbonic Acid Gas.		CO_2	9·29	4·93
Scale-forming Constituents. Calcium	Sulphate	$Ca\ SO_4$	66·576	32·326
	Carbonate	$Ca\ CO_3$	7·649	0·00
	Silicate	$Ca\ SiO_3$	2·458	1·894
Magnesium	Hydrate	$Mg\ (OH)_2$	—	—
	Carbonate	$Mg\ CO_3$	9·586	8·433
	Silicate	$Mg\ SiO_3$	—	—
Ferric Oxide			0·314	0·216
Total			86·583	42·909
Non-Scale-forming Constituents. Sodium	Nitrate	$Na\ NO_3$	—	—
	Chloride	$Na\ Cl$	19·415	20·806
	Sulphate	$Na_2\ SO_4$	0·00	35·390
	Carbonate	$Na_2\ CO_3$	—	—
	Bi-Carbonate	$Na\ HCO_3$	—	—
	Silicate	$Na_2\ SiO_3$	—	—
	Hydrate	$Na\ HO$	—	—
Calcium	Nitrate	$Ca\ (NO_2)_2$	—	—
	Chloride	$Ca\ Cl_2$	—	—
Magnesium	Nitrate	$Mg\ (NO_3)_2$	—	—
	Chloride	$Mg\ Cl_2$	0·978	0·00
	Sulphate	$Mg\ SO_4$	6·061	6·061
Totals			26·454	62·257
Total Mineral Matter			113·037	105·166
Alkalinity			21·139	11·648
Temporary Hardness			21·139	11·648
Permanent Hardness			55·008	28·802
Total Hardness			76·147	40·450
Chemicals required in pounds per 1,000 gallons.*				
Lime		Ca O	3·087	2·100
Soda-Ash		$Na_2\ CO_3$	3·338	4·365
Cost per 1000 gallons		Pence	5·24	—

* The minus signs (-) stands for excess.

ANALYSES.

(*Concluded from page* 54.)

Chemical Analysis.

Wollaston.			Wright.	
Supply.	Delivery.	Delivery less Steam.	Supply.	Delivery.
Grains per Gallon.				
6·21	0·00	—	3·406	0·000
9·610	0·000	0·000	14·174	—
5·592	0·355	0·471	2·033	0·162
1·737	0·000	0·000	1·574	1·778
0·000	0·171	0·227	—	—
5·100	0·000	0·000	3·201	1·635
—	—	—	—	—
0·371	0·024	0·032	—	0·002
22·710	0·550	0·730	20·982	3·577
—	—	—	—	—
7·503	8·013	10·635	1·351	3·897
0·551	7·982	10·594	0·000	12·703
0·000	13·702	18·183	0·000	6·142
—	—	—	0·000	4·630
0·000	1·187	1·575	—	—
0·000	0·502	0·666	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	1·737	0·000
—	—	—	—	—
8·054	31 386	41·653	3·088	27·372
30·764	31·936	42·383	24·070	30·949
13·493	15·161	20·121	7·184	12·173
13·493	0·650	0·862	7·184	3·628
7·065	0·000	0 000	12·246	0·000
20·558	0·650	0·862	19·430	3·628
Chemicals required in pounds per 1,000 gallons.*				
1·641	excess of	—	1·069	0·625
1·071	caustic soda	—	1·856	- 1·295
0·806	- 1·661	—	1·205	—

* The minus signs (-) stands for excess.

APPENDIX IV.

INSTRUCTIONS FOR CONTROLLING CHEMICAL TREATMENT.

Chemicals Required.—Standard Soap solution, Wanklyn's strength (1 cm^3 * = 0·001 *gr.* $CaCO_3$), Standard $\frac{N}{50}$ acid solution (1 cm^3 = 0·001 *gr.* $CaCO_3$), Standard $\frac{N}{50}$ sodium carbonate solution, must be free from bicarbonate. Powdered ammonium oxalate crystals, methyl orange and phenol-phthalein indicators.

Apparati.—Three 50 cm^3 burettes graduated to $\frac{1}{10}$ cm^3. Three 8-oz. glass-stoppered bottles, funnel and filter papers, two white porcelain basins, 4½ inches diameter, and one 70 cm^3 pipette.

I.—70 cm^3 of the water are placed in a clean bottle, and the soap solution run in in small quantities at a time, and the bottle vigorously shaken after each addition. As soon as lather appears, lay the bottle on its side, and observe if the lather persists for five minutes. When this is the case, read off the quantity of soap solution used and, because of some uncombined soap in the lather, subtract 1 cm^3, the remainder is the total hardness, A. When the water requires more than 16 cm^3 of soap solution, it must be diluted with 70 cm^3 of distilled water, and 2 cm^3 must be subtracted from the reading.

II.—Take about 120 cm^3 of the water, add about 4 grains of ammonium oxalate, shake and let it stand for ¼ hour; filter, testing the filtrate with ammonium oxalate to ensure complete precipitation, and take 70 cm^3 of this filtrated water and conduct the soap test as before. The reading less 1 cm^3 is the reduced hardness, B.

III.—70 cm^3 of the water are placed in a porcelain basin, one drop of the methyl orange indicator added, and standard acid dropped in from the burette until the yellow tint just changes to rose pink. Read off the alkalinity (sometimes called temporary hardness), C.

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* cm^3 is used instead of *c.c.*, in conformity with the arrangement recommended (Proceedings 1900, June, page 394).

IV.—70 cm^3 of the water are placed in a porcelain basin and 3 or 4 drops of phenol phthalein added. If the water is acid it remains milky (generally so with natural waters). In this case (1) add the standard sodium carbonate until a pale persistent pink colour is obtained. Read off the phenol phthalein acidity, D.

The water—especially softened water—may turn the phenol phthalein pink.

In this case (2) the 70 cm^3 are titrated with the standard acid until the pink colour is almost destroyed. Read off the phenol phthalein alkalinity, E.

Tests on Hard Water.—Re-agents required in lbs. for softening 1,000 gallons :—

Soda ash.—$0{\cdot}15\ (A - \frac{1}{3}\ B - C)$ lb.

Lime.—Case IV (1). (Water is acid to phenol phthalein) $0{\cdot}085\ (\frac{2}{3}\ B + C + D)$ lb.

Lime.—Case IV (2). (Water is alkaline to phenol phthalein) $0{\cdot}085\ (\frac{2}{3}\ B + C - 2\ E)$ lb.

Using these values the ratio of lime water to total supply is

$$\frac{\text{Lime}}{13 + \text{Lime}}.$$

Tests on the Softened Water.—If an excess of soda ash has been added the amount in excess, $0{\cdot}15\ (A - \frac{1}{3}\ B - C)$ lb., is negative.

When too little soda ash has been added the insufficiency is $0{\cdot}15\ (A - \frac{1}{3}\ B - C)$ lb., as in the untreated water.

If too much lime has been added the amount in excess is $0{\cdot}085\ (2\ C - 2\ E - \frac{2}{3}\ B)$ lb.

If too little lime has been added, the insufficiency is $0{\cdot}085\ (\frac{2}{3}\ B + C - D)$ lb., as in the untreated water.

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This Association was the first institution to establish periodical boiler inspection on a practical basis.

The Association is not a Joint Stock Company. There are no shareholders to whom dividends are paid out of the members' subscriptions, but the income is appropriated solely to promote the direct objects of the Association. The Committee of Management is elected annually at a general meeting of the body of subscribers.

After a boiler has been examined and found fit for its working pressure, the Association gives a pecuniary guarantee of its safety to the extent of £1,000 or £2,000. In the event of explosion the guarantee covers both loss of life and property, as well as claims under the Employers' Liability Act and the Workmen's Compensation Act. The Association does not guarantee boilers on the principle of averages, but as the result of competent scientific inspection. Its object is Prevention, not Compensation; and its fundamental principle is—*No Inspection, No Guarantee.*